MODELING COMPETITION RESPONSES OF PEANUT AND SWEETCORN MULTICROPPING SYSTEMS ON A MALAYSIAN HISTOSOL

BY

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TABLE OF CONTENTS

Page

ACKNOWLEDGMENTS....ii

LIST OF TABLES....vi

LIST OF FIGURES....x

ABSTRACT....xiii

CHAPTERS

I INTRODUCTION....1

II PLANT DENSITY-RESPONSE EFFECT AND MODEL IN TOTAL DRY MATTER AND REPRODUCTIVE YIELDS OF PEANUT AND SWEETCORN AS AFFECTED BY INTER- AND RELAYCROPPING, AND NITROGEN FERTILIZATION ON A TROPICAL HISTOSOL....7

Introduction....7
Materials and Methods....16
Results and Discussion....42

III COMPETITION, ENVIRONMENTAL DIFFERENTIATION AND EFFICIENCY INDICES IN PEANUT AND SWEETCORN INTER- AND RELAYCROPPING SYSTEMS AS AFFECTED BY NITROGEN FERTILIZATION ON A TROPICAL HISTOSOL....131

Introduction....131
Materials and Methods....137
Results and Discussion....146

IV SUMMARY AND CONCLUSIONS....178

APPENDICES

A GLOSSARY....194

B PEANUT AND SWEETCORN TOTAL DRY MATTER AND REPRODUCTIVE YIELDS, LAND EQUIVALENT RATIO, AND AREA-TIME EQUIVALENCY RATIO AT DIFFERENT NITROGEN RATES, CROPPING SYSTEMS, AND PLANTING DENSITIES....199

REFERENCES.....219

BIOGRAPHICAL SKETCH.....228

LIST OF TABLES

Table		Page
1	Cropping history and chemical and physical characteristics of the histosol at the three experimental sites (cycles)	17
2	Monthly temperature and rainfall during January, 1985, to April, 1986, at the Integrated Peat Research Station, MARDI, Pontian, Johor, Malaysia	18
3	Planting distances and configurations; sowing and harvesting dates of mono-, inter-, and relaycropping of peanut and sweetcorn in three cycles of experimentation on a Malaysian histosol	20
4	Peanut total dry matter (TDM) and pod yield per plant as affected by nitrogen rate, system-corn density, and peanut density in three cycles of experimentation on a Malaysian histosol	44
5	Equations of peanut total dry matter (TDM) and pod yield per plant (y) against peanut density (x) for $1 \leq x < 80$ plants $PDMAX^{-2}$ under nitrogen x cropping system environments in three cycles of experimentation on a Malaysian histosol	62
6	Peanut competitive density constant (X_{cp}), potential total dry matter (TDM) or pod yield per plant at intraspecific compeitition free (y_o), and apparent residual of TDM or pod yield per plant (y_{ar}) under nitrogen x cropping system environments in three cycles of experimentation on a Malaysian histosol	64
7	Sweetcorn total dry matter (TDM) and ear yield per plant as affected by nitrogen rate, cropping system, sweetcorn density, and peanut density in three cycles of experimentation on a Malaysian histosol	69
8	Equations of sweetcorn total dry matter (TDM) and ear yield per plant (y) against corn density (x) for $1 \leq x \leq 43.1$ plants $CDMAX^{-2}$ under nitrogen x cropping system environments in three cycles of experimentation on a Malaysian histosol	79

9 Corn competitive density constants (X_{cc}), potential total dry matter (TDM) or ear yield per plant at intraspecific competition free (y_o), and apparent residual of TDM or ear yield per plant (y_{ar}) under nitrogen x cropping system environments in three cycles of experimentation on a Malaysian histosol.....82

10 Peanut total dry matter (TDM) and pod yield per hectare as affected by nitrogen rate, system-corn density, and peanut density in three cycles of experimentation on a Malaysian histosol.....85

11 Equations of peanut total dry matter (TDM) and pod yield per hectare (Y) against peanut density (x) for $1 \leq x \leq 80$ plant $PDMAX^{-2}$ and differentiable response ratio (DRR) under nitrogen x cropping system environments in three cycles of experimentation on a Malaysian histosol.....96

12 Sweetcorn total dry matter (TDM) and ear yield per hectare as affected by nitrogen rate, cropping system, sweetcorn density, and peanut density in three cycles of experimentation on a Malaysian histosol.....110

13 Equations of sweetcorn total dry matter (TDM) and ear yield per hectare (Y) against corn density (x) for $1 \leq x \leq 43.1$ plant $CDMAX^{-2}$ and differentiable response ratio (DRR) under nitrogen x cropping system environments in three cycles of experimentation on a Malaysian histosol.....119

14 Equations of peanut TDM or pod yield per plant (y_p) against peanut competitive density (x_{pp}) and corn density adjusted to $PDMAX^2$ (x_{cp}) in inter- and relaycropping systems in three cycles of experimentation on a Malaysian histosol.....147

15 Equations of sweetcorn TDM or ear yield per plant (y_c) against corn competitive density (x_{cc}) and peanut density adjusted to $CDMAX^2$ (x_{pc}) in inter- and relaycropping systems in three cycles of experimentation on a Malaysian histosol.....150

16 Competition index expressed as plant equivalency in affecting TDM and reproductive yield per plant; and environmental differentiation index in inter- and relaycropping system in three cycles of experimentation on a Malaysian histosol.....154

17 Land equivalent ratio (LER) and area-time equivalency ratio (ATER) with respect to TDM yield per hectare based on monocrop TDM yields at standard corn and peanut densities (as frequently practiced in the area) in the inter- and relaycropping systems in three cycles of experimentation on a Malaysian histosol.....163

18 Average land equivalent ratio (LER) and area-time equivalency ratio (ATER) with respect to TDM yield per hectare based on monocrop TDM yields at standard corn and peanut densities (as frequently practiced in the area); and their respective relative yield proportions in the inter- and relaycropping systems in three cycles of experimentation on a Malaysian histosol.....165

19 Land equivalent ratio (LER) and area-time equivalency ratio (ATER) with respect to reproductive yield per hectare based on monocrop yields at standard corn and peanut densities (as frequently practiced in the area) in the inter- and relaycropping systems in three cycles of experimentation on a Malaysian histosol.....167

20 Average land equivalent ratio (LER) and area-time equivalency ratio (ATER) with respect to reproductive yield per hectare based on monocrop yields at standard corn and peanut densities (as frequency practiced in the area); and their respective yield proportions in the inter- and relaycropping systems in three cycles of experimentation on a Malaysian histosol.....160

B-1 Peanut total dry matter (TDM) and pod yield per plant at different nitrogen rates, density-systems, and peanut densities in three cycles of experimentation on a Malaysian histosol.....199

B-2 Sweetcorn total dry matter (TDM) and ear yield per plant at different nitrogen rates, cropping systems, peanut densities, and corn densities in three cycles of experimentation on a Malaysian histosol.....201

B-3 Peanut total dry matter (TDM) and pod yield per hectare at different nitrogen rates, density-systems, and peanut densities in three cycles of experimentation on a Malaysian histosol.....205

B-4 Sweetcorn total dry matter (TDM) and ear yield per hectare at different nitrogen rates, cropping systems, peanut densities, and corn densities in three cycles of experimentation on a Malaysian histosol.....207

B-5 Land equivalent ratio (LER) and area-time equivalency ratio (ATER) with respect to TDM yield per hectare based on corresponding monoculture TDM yields in the inter- and relaycropping systems in three cycles of experimentation on a Malaysian histosol.....211

B-6 Average land equivalent ratio (LER) and area-time equivalency ratio (ATER) with respect to TDM yield per hectare based on corresponding monoculture TDM yields, and their respective relative yield proportions in the inter- and relaycropping systems in three cycles of experimentation on a Malaysian histosol.....213

B-7 Land equivalent ratio (LER) and area-time equivalency ratio (ATER) with respect to reproductive yield per hectare based on corresponding monoculture yields in the inter- and relaycropping systems in three cycles of experimentation on a Malaysian histosol.....214

B-8 Average land equivalent ratio (LER) and area-time equivalency ratio (ATER) with respect to reproductive yield per hectare based on corresponding monoculture yields, and their respective relative yield proportions in the inter- and relaycropping systems in three cycles of experimentation on a Malaysian histosol.....217

LIST OF FIGURES

Figure		Page
1	Schematic illustration of theoretical response per plant as affected by plant density	37
2	Relationships between peanut total dry matter per plant and plant density in mono-, inter-, and relaycropping environments of Cycle 1 experimentation on a Malaysian histosol	47
3	Relationships between peanut total dry matter per plant and plant density in mono-, inter-, and relaycropping environments of Cycle 2 experimentation on a Malaysian histosol	49
4	Relationships between peanut total dry matter per plant and plant density in mono-, inter-, and relaycropping environments of Cycle 3 experimentation on a Malaysian histosol	51
5	Relationships between peanut pod yield per plant and plant density in mono-, inter-, and relaycropping environments of Cycle 1 experimentation on a Malaysian histosol	55
6	Relationships between peanut pod yield per plant and plant density in mono-, inter-, and relaycropping environments of Cycle 2 experimentation on a Malaysian histosol	57
7	Relationships between peanut pod yield per plant and plant density in mono-, inter-, and relaycropping environments of Cycle 3 experimentation on a Malaysian histosol	59
8	Relationships between sweetcorn total dry matter or ear yield per plant in mono-, inter-, and relaycropping environments of Cycle 1 experimentation on a Malaysian histosol	72

9 Relationships between sweetcorn total dry matter or ear yield per plant in mono-, inter-, and relaycropping environments of Cycle 2 experimentation on a Malaysian histosol....74

10 Relationships between sweetcorn total dry matter or ear yield per plant in mono-, inter-, and relaycropping environments of Cycle 3 experimentation on a Malaysian histosol....76

11 Relationships between peanut total dry matter per ha and plant density in mono-, inter-, and relaycropping environments of Cycle 1 experimentation on a Malaysian histosol....88

12 Relationships between peanut total dry matter and plant density in mono-, inter-, and relaycropping environments of Cycle 2 experimentation on a Malaysian histosol....90

13 Relationships between peanut total dry matter per ha and plant density in mono-, inter-, and relaycropping environments of Cycle 3 experimentation on a Malaysian histosol....92

14 Relationships between peanut pod yield per ha and plant density in mono-, inter-, and relaycropping environments of Cycle 1 experimentation on a Malaysian histosol....101

15 Relationships between peanut pod yield per ha and plant density in mono-, inter-, and relaycropping environments of Cycle 2 experimentation on a Malaysian histosol....103

16 Relationships between peanut pod yield per ha and plant density in mono-, inter-, and relaycropping environments of Cycle 3 experimentation on a Malaysian histosol....105

17 Relationships between sweetcorn total dry matter or ear yield per ha in mono-, inter-, and relaycropping environments of Cycle 1 experimentation on a Malaysian histosol....113

18 Relationships between sweetcorn total dry matter or ear yield per ha in mono-, inter-, and relaycropping environments of Cycle 2 experimentation on a Malaysian histosol....115

19 Relationships between sweetcorn total dry matter or ear yield per ha in mono-, inter-, and relaycropping environments of Cycle 3 experimentation on a Malaysian histosol.....117

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Multiple cropping usually improves productivity in developing countries. However, crop responses and interactions vary because of complex time and space resource competition. The objective of this field study was to provide a crop response vs. crop density model for quantifying responses within peanut and sweetcorn on a tropical Malaysian histosol.

The treatments in the 3-cycle study (1985 to 1986) were nitrogen (N) (0 and 150 kg ha^{-1}), cropping systems (CS) [mono-, inter-, and relaycropping of peanut (Arachis hypogaea L.) and sweetcorn (Zea mays L.)], and plant density of sweetcorn (2.7 to 13.3 plants m^{-2}) and peanut (5 to 80 plants m^{-2}). Corn and peanut total dry matter (TDM) and reproductive yields [per plant and per hectare (ha)] were increased with N. Corn reduced inter- and relaycrop peanut TDM and pod yields. Intercrop peanut reduced corn TDM and ear yields, especially without N, whereas relaycrop peanut had little effect on corn yields.

Plant response vs. density (x, plants per competitive area) relationship was modeled based on two assumptions: (a) yield per plant (y) will be constant (y_o) at competition-free densities and nonzero [apparent residual (y_{ar})] at high densities, and (b) the rate of decrease of plant response to competitive density is proportional to ($y - y_{ar}$). The proportionality factor was the reciprocal of the competitive density constant (X_c). The yield per area (Y) vs. density relationship is $Y = yx$. This model was extended to develop competition index (CI) and environmental differentiation index (EDI) between component crops in inter- and relaycroppings.

The response (TDM and reproductive yield) per plant vs. density relationships among crops, cycles, CS, and N decreased exponentially to y_{ar} with increasing density. The response per area relationships of peanut TDM and pod and corn TDM were either asymptotic, near asymptotic, or increasing trend (y_{ar} became important relative to y_o), whereas the corn ear response was parabolic (low y_{ar} relative to y_o). Corn density optimum was low in non-N plots (low X_c). The CI values reveal that corn was more competitive than peanut. Without N, corn and peanut were in the same intercropping environment (EDI = 1). With N, they differentiated the environment by high- vs. low-light regimes (EDI >> 1). The differentiation in N-relaycropping was due to time-related factors and soil N (EDI >>> 1).

The y vs. x and Y vs. x models and CI and EDI values were applicable to different environments (CS x N), crops (corn vs. peanut), and cycles, and thus are likely applicable to other environments.

CHAPTER I
INTRODUCTION

World population has increased at the average rate of 1.9% per year during the period of 1965 through 1980 to 4,836,960,000 people (FAO, 1985). This warrants the necessary increase in food production to support the increasing population. To improve the world food supply, strategies that increase and diversify food production are crucial. Apart from a highly mechanized monoculture which is common in industrial countries, multiple cropping farming (inter-, mixed-, relay- and rotational-cropping) as practiced in developing countries is an additional avenue (Andrews and Kassam, 1976) for increasing total world food production.

Multiple cropping systems benefit farmers with small-holdings and limited financial resources (Ahmed and Gunasena, 1979). Risks of monocropping failures caused by unpredictable environmental and economic problems can probably be reduced by practicing multiple cropping. The complete or partial combination of two or more plant species which spatially and/or temporally differ in microenvironmental needs and adaptation should be biologically and economically beneficial and more efficient. Therefore, environmental and genetic differences potentially can be exploited by developing appropriate cropping strategies for higher crop productivity per unit of land area

and time. It is envisaged, hypothetically, that (a) two or more plants which differ in microenvironmental needs will compete for resources under stress situations, and (b) two or more plants which are physiologically and agronomically compatible in combination are biologically more efficient (area and time) than monocultures.

In view of the growing importance of multiple cropping, particularly in developing countries, several researchers have conducted multiple cropping and competition studies covering both theoretical and applied aspects directed toward total system productivity (Willey, 1979a, 1979b). Some areas of study were (a) criteria for assessing yield advantages (Willey, 1979b); (b) competition functions: relative crowding coefficient (de Wit, 1960), competition index (Donald, 1963), and aggressivity (McGilchrist and Trenbath, 1971); (c) efficiency: relative yield total (RYT) (de Wit and van den Bergh, 1965), land equivalent ratio (LER) (IRRI, 1974; Willey, 1979a; Mead and Willey, 1980) and area-time equivalency ratio (ATER) (Hiebsch and McCollum, 1987); (d) resource use: light (Crookston, 1976; Willey and Roberts, 1976), water and nutrient (Trenbath, 1974); (e) yield stability (Trenbath, 1974; Harwood and Price, 1976; Fisher, 1977); (f) plant density and spatial arrangement (Willey and Osiru, 1972); and (g) genotype identification (Francis et al., 1976; Davis and Garcia, 1983; Knauft, 1984). Various workers have used different plant densities of the same crops for studying the above aspects which resulted in different emphases and perspectives. In multiple cropping, two aspects are frequently emphasized, namely, competition and yield advantage (or efficiency). Furthermore,

competition among plants may be either intraspecific or interspecific, or some combination of each. Duncan (1984) indicated that most studies have used plant population (plant density) as the independent variable in evaluating the effect of competition on plant yield. Willey (1979b) pointed out that where intercropping gives a yield advantage, the total population optimum may be higher than that of either sole crop. This tendency was also shown by other workers (Kassam, 1973; IRRI, 1974; Baker and Yusuf, 1976; ICRISAT, 1977). Willey (1979b) further suggested that the cause of a higher optimum total population in intercropping systems was presumably due to better resource utilization, which then was reflected in higher yield advantage. Plant density in a given environment can be considered to be the governing factor in multiple cropping studies, where environment is defined as the resultant combination of all cultural factors (for example, fertilization, cropping system, etc.) in the given locality and soil type. Agronomists wish to define crop yield vs. density relationships or models so that future relationships may be predicted easily from minimum data input (Willey and Heath, 1970). However, there are still only a few plant response vs. density models for multiple cropping environments. Willey and Heath (1970) indicated that the majority of the models were developed from monoculture situations. Generally, the available models can be grouped into four categories, viz., (a) polynomial equations (Hudson, 1941; Warren, 1963; Sharpe and Dent, 1968); (b) geometric equations (Warne, 1951; Kira et al., 1953); (c) reciprocal equations (Shinozaki and Kira, 1956; de Wit and Ennik, 1958; Bleasdale and Nelder, 1960;

de Wit, 1960; Holliday, 1960a; Farazdaghi and Harris, 1968); (d) exponential equations [Mitscherlich, 1919 (as cited by Willey and Heath, 1970); Duncan, 1958, 1984; Carmer and Jackobs, 1965]. The parameters of the models in (a), (b), (c), and (d) range from none, few, or unclear, to those that appear to be biologically meaningful.

The general objective of this study was to propose new approaches that would be based on observed agronomic responses in developing a plant response vs. density model under mono-, inter-, and relaycropping environments. A criterion of the model was to rectify some inadequacies that seemed to be present in the earlier models. The model was further used to develop indices for measuring effect and strength of competition and the degree of environmental differentiation among the component crops used. Accordingly, the research on mono-, inter-, and relaycropping of peanut (Arachis hypogaea L.) and sweetcorn (Zea mays L.) conducted on Malaysian peat (tropical oligotrophic histosol) conditions served as a case study for proposing new approaches.

Since Malaysia has a humid tropical climate, i.e., moderately high radiation, warm temperature, and sufficient rainfall throughout the year, it should be conducive to growth of corn, which has the C4 photosynthetic pathway. Peanut, a C3 photosynthetic pathway crop, characterized by relatively low-light saturation stress tolerance and photoperiod insensitivity, was selected as the understory crop in combination with corn to achieve high total productivity per unit area and time, as well as yield stability. Thus, the strategy of this

study was to characterize the exploitation of a C4 and C3 crop-plant association.

In cereal-legume intercropping, fertilizer nitrogen (N) may still be necessary, since the cereal component depends heavily on N for maximum yield (Ofori and Stern, 1986). However, there are still conflicting results on the effects of applied N to the yields of component crops in a cereal-legume system. For example, Searle et al. (1981) indicated that N did not affect maize grain yield, and found no interaction between cropping pattern and N in maize-soybean and maize-peanut intercropping systems. On the other hand, yields of maize (Ofori and Stern, 1986) and sorghum (Wagmare and Singh, 1984) in the maize-cowpea and sorghum-pigeonpea associations were increased with N fertilization. Furthermore, information on the effect of N on multiple cropping on peat soil, especially on peanut and corn inter- and relaycropping systems, is still lacking. Under conditions of high soil carbon:nitrogen ratio and acidity (Parbery and Venkatachalam, 1964; Joseph et al., 1974) and lack of peanut nodulation (Shamshuddin, 1984), the degree of competition between peanut and corn in cropping associations on N- and non-N-fertilized peat soil is unknown.

In this study, the cropping duration between peanut-corn inter- and relaycropping was different, being 100 and 153 days, respectively. With respect to intercropping, Willey (1979b) indicated that higher densities are most likely needed for greatest benefits where there are large temporal differences in growth patterns of component crops. In measuring biological efficiency of the various intercrops, Hiebsch and McCollum (1987) proposed area-time equivalency

ratio (ATER), developed by integrating time into the land equivalent ratio (LER) calculation. They compared ATER to the widely used LER where cropping duration is not considered. In this study, both LER and ATER efficiency indices were computed to determine the significance of duration of crops in different peanut-corn production systems under a tropical peat environment. The time factor in multiple cropping systems can be important.

Specifically, the objectives of this study were

(a) to determine and model density-response effects with respect to total dry matter and reproductive yields of peanut and sweetcorn in mono-, inter-, and relaycropping as affected by N fertilization on a tropical histosol (oligotrophic peat); and

(b) to develop competition indices and environmental differentiation index, and determine biological efficiencies of inter- and relayplanted peanut in sweetcorn, specifically as related to plant density and N fertilization under the above soil environment.

A glossary of terms used in multiple cropping systems and in plant competition research is included as Appendix A.

CHAPTER II

PLANT DENSITY-RESPONSE EFFECT AND MODEL IN TOTAL DRY MATTER AND REPRODUCTIVE YIELDS OF PEANUT AND SWEETCORN AS AFFECTED BY INTER- AND RELAYCROPPING, AND NITROGEN FERTILIZATION ON A TROPICAL HISTOSOL

Introduction

Multiple cropping systems, including inter- and relaycropping, are widely practiced by farmers in tropical regions at all levels of agricultural technology (Andrews and Kassam, 1976). The development and application of new technology for multiple cropping systems for increased food production is essential in many areas (Papendick et al., 1976). Generally, the technologies most needed are ones related to type of crop (or varieties), mixture system (temporal and/or spatial), optimum planting density, and fertilization. Whether it is realized or not, most multiple cropping systems, especially inter- or relaycropping, constitute a combination of overstory C4 and understory C3 plants. Intercropping is defined as growing two or more crops simultaneously where one or more crops are planted in rows; while in relaycropping, a similar procedure is used except that the second crop(s) is planted after the first has reached its reproductive growth stage but before harvest (Andrews and Kassam, 1976). Corn (Zea mays L.), sorghum (Sorghum bicolor L.) and millet (Pennisetum typhoides L.) are common overstory C4 plants (Crookston, 1976; Edje, 1980; Nambiar et al., 1983), whereas grain legumes (C3) such as peanut

(Arachis hypogaea L.), bean (Phaseolus vulgaris L.), soybean (Glycine max Merrill) and cowpea [Vigna unguiculata (L.) Walp] are commonly used as the understory crops in inter- or relaycropping systems (Edje, 1980; Nambiar et al., 1983).

Ludlow (1976) indicated that when net photosynthesis is not limited by environmental and physiological factors, the light response curve of C4 grass leaves is not light saturated at midday summer solar irradiance, whereas saturation occurs in C3 legumes at a third to a half of full solar irradiance. Hence, in intercropping, the over- and understory canopies should consist of components that are compensatory in light utilization (Willey, 1979a). This leads to the usual combination between tall-C4 and short-C3 crops in intercropping (Allen et al., 1976; Crookston, 1976). Specifically, Crookston (1976) indicated that corn and sorghum have higher temperature requirements, respond better to higher irradiance, and remove carbon dioxide from the air more effectively. The high plant density of the C4 (overstory) crop may cause heavy mutual shading of overstory crop and also reduce substantially light received by the understory C3 crop. Allen et al. (1976) pointed out that radiation quality (730 nm/660 nm ratio) may affect morphogenesis of understory crops in intercropping. The shading of peanut by pearl millet, maize or sorghum intercrops caused a reduction in nodulation and nitrogen fixation as a consequence of decrease in photosynthesis of peanut (Nambiar et al., 1983). However, in cereal-legume intercropping, legumes symbiotically fix atmospheric N for at least some of their N requirement (Mutsaers, 1978; Malithano and Leeuwen, 1980). Brown

(1978) showed that C4 plants have a greater N use efficiency than do C3 plants. Kurtz et al. (1952) revealed that high N and water availability could reduce competition between an understory crop and corn where other immobile nutrients such as potassium and phosphorus are sufficient. However, they further indicated that sufficient N and water did not completely eliminate competition since corn yields under monocropping conventional systems were 15% greater than those under intercropping systems. This finding suggests competition for other growth limiting factors. Spitters (1983a) found a niche differentiation value of 4.3 in maize-groundnut intercropping which reveals that intraspecific is greater than interspecific competition, and hence the species were only partly limited by the same set of resources. There are some advantages of intercropping compared to monoculture as measured by the increased total yield (Willey and Osiru, 1972; Crookston, 1976; Willey, 1979a; Rao and Willey, 1980), reduced risks of total crop failure (Ahmed and Rao, 1982), and improved balance in diet via diversified species (Akhanda et al., 1977; Mead and Willey, 1980). All of the above indicate combining compatibility between C4- and C3-crop plants towards higher productivity of inter- or relaycropping systems via manipulation in type of crop plant grown, mixture system (relay- or intercropping), planting density, and fertilization.

Some researchers indicated that corn grain yield per unit land area was not affected by intercropped peanut (Akhanda et al., 1977; Edje, 1980; Searle et al., 1981). This might be due to taller maize, with its larger frame maintained a competitive advantage over the slow

growing and shorter peanut (Edje, 1980). However, Knauft (1984) found that intercrop maize with peanut grown on Arredondo fine sand soil had lower yield (2070 to 3530 corn grain kg ha^{-1}) compared to maize monoculture (3060 to 5730 kg ha^{-1}). Correspondingly, several findings showed pod yield reduction in intercrop peanut compared to that in peanut monoculture (Evans, 1960; Syarifuddin et al., 1974; Akhanda et al., 1977; Baker, 1978; Edje, 1980; Searle et al., 1981; Knauft, 1984). In sweetcorn, Beste (1976) found an acceptable ear yield when cocropped with soybean; however, the yield was reduced at high soybean density. Edje (1980) and Searle et al. (1981) showed that the total dry matter (TDM) of corn was also not affected by intercrop peanut whereas the peanut TDM was greatly reduced by corn compared to peanut monoculture.

Under corn-peanut intercropping or associative culture, several workers indicated that corn grain yield per unit land area increased with increasing corn density. The corn density ranges were 24,000 to 72,000 plants ha^{-1} for an early maturing hybrid (Akhanda et al., 1977); 10,000 to 40,000, 15,000 to 60,000, and 30,000 to 120,000 plants ha^{-1} for Harapan (110 days maturity), Kretek (85 days) and Madura (75 days) cultivars, respectively (Syarifuddin et al., 1974); 13,887 to 27,777 plants ha^{-1} (Mutsaers, 1978); and about 15,500 to 28,500 plant ha^{-1} at Ilonga, Tanganyika (Evans, 1960). On the other hand, about parabolic responses were found for medium and late maturing varieties (Akhanda et al., 1977) and for corn grown at Mwanhala, Tanganyika (Evans, 1960). In a monoculture environment, Fery and Janick (1971) indicated that the corn grain yield vs. density

(2,375 to 151,957 plants ha^{-1}) relationships followed asymmetric parabolic responses in both square and row spacing treatments. They found a similar trend for ear yield of 'Golden Beauty' sweetcorn. Warren (1963) used a quite symmetric parabolic relationship in describing 'Golden Cup' sweetcorn ear yield across a density range of 17,300 to 79,100 plants ha^{-1}. The TDM of grain corn increased asymptotically with increasing density, whereas sweetcorn seemed first to increase rapidly, then plateau and increase again at a lower rate with increasing density in row spacing treatments (Fery and Janick, 1971). This latter trend was clearly observed in TDM yield harvested at about 58 days after planting where the densities ranged from 7,000 to 700,000 plants ha^{-1} (Williams et al., 1965).

Evans (1960) indicated that peanut yield in a peanut-corn intercropping system was not affected by peanut density over the range of ca. 15,500 to 28,500 plants ha^{-1} at Ilonga, Tanganyka; however the yield was increased over low (ca. 65,000 plants m^{-2}) to medium peanut densities (ca. 93,500 plants m^{-2}) at Mwanhala, Tanganyika. In a monoculture environment, Lipscomb et al. (1965) reported that with the upright growth habit variety of peanut (Dixie Spanish), the pod and hay yields were significantly increased over seeding rates of 107,637 to 322,910 seeds ha^{-1} (91.4- to 30.5-cm row spacings, respectively) over a 3-year average. They found a similar trend for runner type (Early Runner) but without statistical significance. Norden and Lipscomb (1974) indicated that "bunch" lines had a 16% yield increase in 46- over 91-cm rows, while runner types only had a 5% increase. Knauft et al. (1981) found that pod yields of

'Florunner' and 'Florigiant' at 10.2 and 15.2 cm intrarow spacings (107,264 and 71,980 plants ha^{-1}, respectively) were significantly higher than that at 30.5 cm (35,872 plants ha^{-1}) in six years of research. They further showed that 'Early Bunch' yield was significantly higher at a 15.2 cm spacing whereas the yields were intermediate and lowest at 10.2 and 30.5 cm, respectively, i.e., a parabolic response. Ishag (1970) reported that the highest yield of the 'Ashford' variety of peanut was obtained at the highest density (166,667 plant ha^{-1} or 40 cm x 15 cm spacing) whereas the highest yield of the 'Barberton' variety was at 111,111 plants ha^{-1} (60 cm x 15 cm). In general, several researchers found an increasing trend in peanut yield within their respective experimental density ranges (Cox and Reid, 1965; Saint-Smith, 1969; Enyi, 1977; Langford, 1977; Buchanan and Hauser, 1980; Mozingo and Coffelt, 1984). The higher plant densities might have been the results of higher seeding rates or narrow-row spacings. In summary, peanut yield per unit area vs. density response can either be an increasing trend, parabolic, or asymptotic, largely depending on plant type, environment, management level, or range of experimental plant densities.

Ofori and Stern (1986) reported increases in maize grain and TDM yields with applied N fertilizer (0 to 100 kg N ha^{-1}) in monoculture and intercropping with cowpea on Dardanup silt loam soil. In a study on maize-peanut intercropping on the dark reddish brown light soil, Searle et al. (1981) indicated a significant increase and no effect on TDM and corn grain yields of both sole and intercrop with applied N (0

to 100 kg N ha^{-1}), respectively. Increased corn grain yield due to applied N in monoculture environment was reported in other studies (Duncan, 1958; Agboola and Fayeemi, 1971).

In corn-peanut intercropping environment, peanut pod yield was reduced with increasing applied N (Searle et al., 1981; Nambiar et al., 1983). Searle et al. (1981) indicated that this was due to inhibition of peanut nodulation resulting in less N fixation, both directly from increased soil N and indirectly by stimulation of maize growth and greater shading of intercrop legume. The latter cause was also indicated by Nambiar et al. (1983). In spite of some reports indicating monoculture peanut yield decreases with high N application (Pancholy and Basha, 1982), Reddy et al. (1981) and Wynne et al. (1979) showed yield increases with split N applications on sandy soil. Selamat and Gardner (1985) reported a linear increase in pod and TDM yields of nonnodulated peanut to applied N (0 to 240 kg N ha^{-1}) on a Lakeland soil, compared to no significant response of nodulating varieties. On a Malaysian peat soil (oligotrophic type), i.e., with high carbon:nitrogen ratio and high acidity, Chew et al. (1979) reported that with N and copper sulphate fertilizations (34 N and 20 $CuSO_4$ kg ha^{-1}, respectively) and at 333,333 plants ha^{-1}, peanut seed yield was 743 to 1120 kg ha^{-1}. From the above, it is deduced that where soil N is low, N fertilization appears to be necessary for increasing peanut and corn yields. However, experimental information on the TDM and reproductive yields of peanut and sweetcorn in association as affected by N and plant density on the tropical oligotrophic peat soil environment is lacking.

In this study, several combinations of cropping system (pattern) by N fertilization were selected to give different environments under peat soil conditions. There are two approaches in dealing with plant density within the context of multiple cropping, i.e., (a) the replacement series (association that formed by replacing a proportion of one crop with an equivalent proportion of another) and (b) the additive series (the total population of mixture is greater then either monoculture). Some experiments have indicated that where intercropping gave a yield advantage, the total population might be higher than that of either monoculture (Willey and Osiru, 1972; Willey, 1979b; Willey and Rao, 1980). The additive series is more flexible, since it can consist of any set of densities of component crops in the association. However, only a few proposed models of plant response vs. density relationships for component crops in multiple cropping systems have been proposed to date.

In a generalized reciprocal model (without a constant power applied to either yield per plant or to density) (Shinozaki and Kira, 1956; Bleasdale and Nelder, 1960; de Wit, 1960; Holliday, 1960a, 1960b; Farazdaghi and Harris, 1968), the asymptotic yield per unit area vs. density relationship is indicated. This model does not fit to parabolic or increasing (not delayed asymptotic) yield per unit area trends at high density. By applying a certain constant power to yield per plant (Bleasdale and Thompson, 1966) or plant density (Farazdaghi and Harris, 1968), the parabolic relationship could be obtained, but the interpretation of factor indicative of environmental

potential was biologically less obvious (Willey and Heath, 1970). The exponential response model (Duncan, 1958, 1984; Carmer and Jackobs, 1965) was not applicable to very high density. Furthermore, it cannot be used to describe asymptotic (Willey and Heath, 1970) and increasing trend (not delayed parabolic) yield per unit area vs. density relationships. In looking at yield per plant vs. density models, generally both reciprocal and exponential (except Duncan, 1984) related equations showed maximum yield per plant at density near or equal to zero, whereas yield per plant practically levels off at densities free of competition (Willey and Heath, 1970). In the polynomial models (Hudson, 1941; Warren, 1963; Sharpe and Dent, 1968), the parameters have either little or no biological meaning (Willey and Heath, 1970).

The general objective of this study was to develop a plant response vs. density model of component crops under both mono- and multiple cropping environments. The model was designed to rectify some inadequacies of earlier proposed models developed primarily under monoculture situations. As model and experimental information on peanut and sweetcorn mono-, inter-, and relaycropping on peat soil is still lacking, the specific objectives of this study were therefore

(a) to determine the TDM and reproductive yields (per plant and per unit area) as affected by plant density, N fertilization, and cropping system (mono-, inter-, or relaycropping) under the Malaysian histosol conditions and

(b) to develop a plant response vs. density model in N x cropping system situations on the above soil conditions.

Materials and Methods

Experimental Techniques

The experiment was conducted on a peat (Histosol) soil of more than 1.5 m depth (oligotrophic type, i.e., low in mineral but high in acidity) at the Integrated Peat Research Station of the Malaysian Agricultural Research and Development Institute (MARDI) in 1985 and 1986. The experiment was repeated in three cropping cycles, that is, during 26 May to 25 October, 1985, 24 June to 25 November, 1985, and 12 November, 1985, to 24 April, 1986. Each cropping cycle study was conducted on a different set of plots. Acidity (pH), N, phosphorus (P), potassium (K), carbon:nitrogen ratio (C:N), moisture content and bulk density measurements of the soil prior to experimentation are shown in Table 1. Monthly rainfall and minimum and maximum monthly temperatures are shown in Table 2. Treatment combinations in four replications (39.0 m x 20.0 m per replication) per cropping cycle consisted of (a) nitrogen (N) rates (0 vs. 150 kg ha^{-1}) in main plots (39.0 m x 10.0 m per main plot); (b) sweetcorn (corn) cv. 'Thaisupersweet' densities [2.7, 5.3, and 13.3 plants m^{-2} (26,667, 53,333, and 133,333 plants ha^{-1}, respectively)] x cropping systems (CS) [corn monoculture, two peanut monocultures (planted at peanut inter- and relayplanting dates), peanut-sweetcorn intercropping, and peanut-sweetcorn relaycropping] in sub-plots (3.0 m x 10.0 m per sub-plot); and (c) five peanut cv. 'Matjam' densities [5, 10, 20, 40, and

Table 1. Cropping history and chemical and physical characteristics of the histosol at the three experimental sites (cycles).

	Cycle 1	Cycle 2	Cycle 3	$LSD_{0.05}$
Previous crop	left fallow	corn	cassava	-
N (%)	1.16	1.48	1.30	0.29
P (ppm)	34.0	9.4	14.8	9.2
K [meq $(100\ g)^{-1}$]	0.57	0.31	0.30	0.18
C (%)	28.1	29.3	27.2	2.1
C:N	24.8	19.8	21.5	5.1
Water content ($cm^3\ cm^{-3}$)	0.85	0.60	0.78	0.06
Bulk density ($g\ cm^{-3}$)	0.12	0.19	0.25	0.05
pH, before liming	3.7	3.5	3.5	0.2
pH, after liming[a]	4.1	4.6	4.05	0.4

[a] Applied at the rate of 8000 kg ha^{-1} of ground magnesium limestone at two weeks before sowing.

Table 2. Monthly temperature and rainfall during January, 1985, to April, 1986, at the Integrated Peat Research Station, MARDI, Pontian, Johor, Malaysia.

Year	Month	Maximum temperature	Minimum temperature	Rainfall
		- - °C - -	- - °C - -	- - mm - -
1985	Jan.	31.8	20.3	220.5
	Feb.	32.4	21.5	450.8
	Mar.	32.1	21.6	396.4
	Apr.	32.1	22.0	146.7
	May	32.3	22.3	195.0
	June	32.2	21.5	96.2
	July	31.1	21.2	138.5
	Aug.	31.7	21.2	191.8
	Sept.	31.3	21.6	236.0
	Oct.	31.1	21.9	414.2
	Nov.	31.2	22.0	272.8
	Dec.	31.2	21.9	125.1
1986	Jan.	30.1	21.7	362.5
	Feb.	32.4	20.5	84.7
	Mar.	30.7	21.7	337.8
	Apr.	32.5	22.1	14.6

Source: Meteorological Department, Petaling Jaya, Selangor, Malaysia.

80 plants m^{-2} (50,000, 100,000, 200,000, 400,000, and 800,000 plants ha^{-1}, respectively)] in sub-sub-plots (3.0 m x 2.0 m per sub-sub-plot). Row spacing in all cases was 75 cm for corn and 37.5 cm for peanut (Table 3). Adjacent to each main-plot, single monoculture corn and peanut (corresponded to inter- and relayplanting dates) plots were included for CDMAX and PDMAX determinations, i.e., corn and peanut maximum distances at intraspecific competition-free, respectively.

Since the row widths of corn and peanut were fixed at practical values applicable for multiple cropping, the plant densities were increased by decreasing the distance between plants within rows. Captan (cis-N-((trichloromethyl)thio)-4 cyclohexene-1,2-dicarboximide) treated peanut seeds and BHC (benzynehexachloride) treated corn seeds were simultaneously hand planted in mono- and intercropping, while relaycrop peanut seeds were sown at one day after 50% tasseling in the corn [at 53 days after planting (DAP)] in the relaycropping treatment. The planting distances, configurations, and dates are shown in Table 3.

Ground magnesium limestone (8000 kg ha^{-1}) was incorporated into soil during rotovation at two weeks before sowing. Fertilizers at the rates of 26.2, 66.3, 8.0, 8.1, 7.4, 7.3, 12.1, 0.4, and 1.0 kg ha^{-1} of P, K, Cu, Zn, Fe, Mn, Mg, B and Mo, respectively, were applied just prior to planting. Nitrogen (150 kg ha^{-1}) as urea was applied in two equal splits (at 0 and 28 DAP) to N-treated main plots. Weeds were controlled with the premergence herbicide alachlor [2-chloro-N-(2,6-diethylphenyl)-N-(methoxymethyl) acetamide] at the rate of 2.0 kg a.i.

Table 3. Planting distances and configurations; sowing and harvesting dates of mono-, inter-, and relaycropping of peanut and sweetcorn in three cycles of experimentation on a Malaysian histosol.

Cycle	Cropping system	Planting distances (cm x cm)	Planting configurations	Sowing dates†	Harvesting dates*
1	Sweetcorn Monocropping	10,25,50x75	Solid planting	5/26/85	8/13/85
	Peanut Monocropping-(I)°	3.3, 6.7, 13.3, 26.7, 53.3 x 37.5	Solid planting	5/26/85	9/2/85
	Peanut Monocropping-(R)¶	3.3, 6.7, 13.3, 26.7, 53.3 x 37.5	Solid planting	7/17/85	10/25/85
	Intercropping	As in respective monocroppings	Two peanut rows between corn rows	Corn: 5/26/85 Peanut: 5/26/85	Corn: 8/13/85 Peanut: 9/2/85
	Relaycropping	As in respective monocroppings	Two peanut rows between corn rows	Corn: 5/26/85 Peanut: 7/17/85	Corn: 8/13/85 Peanut: 10/25/85
2	Sweetcorn Monocropping			6/24/85	9/13/85
	Peanut Monocropping-(I)			6/24/85	10/2/85
	Peanut Monocropping-(R)	As in cycle 1	As in cycle 1	8/17/85	11/25/85
	Intercropping			Corn: 6/24/85 Peanut: 6/24/85	Corn: 9/13/85 Peanut: 10/2/85
	Relaycropping			Corn: 6/24/85 Peanut: 8/17/85	Corn: 9/13/85 Peanut: 11/25/85

3	Sweetcorn Monocropping			11/12/85	1/29/86
	Peanut Monocropping-(I)			11/12/85	2/22/86
	Peanut Monocropping-(R)	As in cycle 1	As in cycle 1	1/12/86	4/24/86
	Intercropping			Corn: 11/12/85 Peanut: 11/12/85	Corn: 1/29/86 Peanut: 2/22/86
	Relaycropping			Corn: 11/12/85 Peanut: 1/12/86	Corn: 1/29/86 Peanut: 4/24/86

† and *: Sowing and harvesting were completed after 3 to 4 days from the dates shown.

° and ¶: Monocroppings that correspond to inter- and relayplanting dates, respectively.

ha^{-1}, and by handweeding. Granule carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate) at 0.5 kg a.i. ha^{-1} was applied at two to three DAP to give initial seedling protection against insects. Furthermore, insect pests were controlled by using several insecticides, viz., carbaryl (1-napthyl-N-methyl-carbamate), methamidophos (0,5-dimethyl phosphoramidothioate) and dimethoate [0,0-dimethyl S-(N-methylcarbamoylmethyl) phosphorodithioate] at the rates of 1.7, 0.5, and 0.9 kg ha^{-1}, respectively, which were sprayed alternately at 7- to 10-day intervals. In addition, granule carbofuran at 0.5 kg a.i. ha^{-1} was applied directly into the corn leaf whorl at 30 to 31 DAP as a preventive measure against insects. Fungal diseases, for example leaf rusts (Puccinia arachidis) and leaf spots (Cercospora spp.) on peanut leaves, were controlled by alternately spraying captan, benomyl (methyl 1-(butylcarbamoyl)-2-benzimi dazolecarbamate), and mancozeb (ethylene bis dithiocarbamato zinc) at the rates of 1.0, 0.3 and 0.9 kg ha^{-1}, respectively, at 7- to 10-day intervals. The plots were also irrigated as needed.

Corn was harvested manually at about 80 DAP (Table 3). The fresh total above ground biomass (FTB) from each harvest plot (HP) [1.5 m x 1.0 m (from the sub-sub-plot) for the inter- or relaycropping and 1.5 m x 4.0 m (from the sub-plot) for the monocropping] was weighed and two representative plants were reweighed and plant height was determined. These two plants were separated into stems plus tassels, leaves and ears (EAR), and then reweighed. Component samples were dried in an oven at 70°C and weighed for total dry matter fraction (DF) determination. The ears of the remainder of each plot after

sub-sampling were weighed (EARR). From the above procedures, the total above ground dry matter (TDM) per plant and per hectare (ha) were calculated as (FTB x DF)/(plants per HP) and FTB x DF x CF, respectively, where CF is the conversion factor from yield per HP to yield per ha basis. The ear yield per plant and per ha were calculated as (EAR + EARR)/(plants per HP) and (EAR + EARR) x CF, respectively. All corn plants remaining after sampling were removed by cutting at the plant base to prevent shading of the understory inter- and relayplanted peanut. Mono- and intercrop peanut were harvested at about 100 DAP (Table 3). The fresh total biomass (PFTB) from each harvest (HP) plot [1.5 m x 1.0 m (from the sub-sub-plot)] was weighed and two representative plants were reweighed and separated into leaves, stems plus petioles, roots, and pods. Each sample, except pods, were force dried in an oven at 70°C and weighed. Pod samples were first dried at 30°C in an oven and then weighed (POD), and then they were force dried at 70°C in an oven and weighed. From the above procedures, plant part fractions and total dry matter fraction (DF) were determined. The remainder of each plot after sub-sampling was sun dried for about 3 to 5 days and manually picked. The pods were further dried at 30°C in an oven then weighed (PODR). The above procedure was also repeated for the relayplanted peanut which was harvested at about 153 days after corn planting (Table 3). From the above procedures, the total dry matter (TDM) per plant and per ha were calculated as (PFTB x DF)/(plants per HP) and PFTB x DF x CF, respectively. The pod yield per plant and per ha were calculated as (POD + PODR)/(plants per HP) and (POD + PODR) x CF, respectively.

All data were statistically analyzed by using the SAS procedure (SAS, 1985) and significance was tested by the F-test. Further, least significant difference (LSD) (Cochran and Cox, 1957) was used for mean comparisons. Regression models which were developed from mathematical derivations based on agronomic and biological considerations were then used in describing the relationships of yield (pod, ear, or TDM) per plant and per ha to plant density of respective component crops under N x cropping system environments. The derivations of the models are discussed in the following sections.

Theoretical and Mathematical Considerations

Per plant basis. Most researchers have found that the whole plant TDM and each plant component decrease with increasing plant density. Duncan (1958) indicated that the yield reduction is caused by a decrease in the supply of the environmental factors of yield that each plant is forced to share with its competing neighbors. In presenting mathematical relationships between yield and plant density, the majority of researchers propose a basic relationship between mean yield per plant and density (Willey and Heath, 1970). In the following discussion, reproductive yield per plant or TDM per plant will be designated as y, whereas plant density (or population) will be x. In the later section, TDM or reproductive yield per unit area will be shown as Y. The models will be reviewed according to year of origin.

Mitscherlich (1919) [as cited by Willey and Heath (1970)] proposed a law of physiological relationship between yield per plant

and the supply of essential growth factor (f), mathematically expressed as

$$\frac{dy}{df} = (M - y)C \tag{1}$$

where M and C are maximum yield per plant and a constant, respectively. Integration yields

$$y = M(1 - e^{-Cf}) \tag{2}$$

Later, he suggested that his equation could be applied generally to the relationship between space and plant growth, expressed as

$$y = M(1 - e^{-ks}) \tag{3}$$

where s and k are space and general space constant, respectively. Warne (1951) proposed a linear relationship between the logarithm of root yield per plant (beet, parsnip, and carrots) and the logarithm of a distance between plants in the row where row width was constant, and mathematically expressed as

$$y = A(S)^{b} \tag{4}$$

where A and b are constants, and S is the along-row space available per plant. Kira et al. (1953) proposed a linear relationship between the logarithm of total yield per plant and the logarithm of density in a soybean experiment, which was finally expressed as a reciprocal (simple hyperbolic) relationship as

$$yx^{a} = k \tag{5}$$

where x, a and k are the plant density, the competition-density index and constant, respectively. Shinozaki and Kira (1956) suggested an equation which was derived from a simple logistic growth curve and the law of constant final yield, and mathematically expressed as

$$\frac{1}{y} = a + bx \tag{6}$$

where a and b are constants. They suggested the inclusion of δ in Eq. (6) so that yield per plant at densities free of competition could be simultaneously explained by the equation. The value of δ should be chosen so that at high densities, δ would be negligible compared to x. The δ value would be effective at low densities, and result in constant yield per plant at low densities (competition-free). This equation can be expressed as

$$\frac{1}{y} = a + b(x + \delta) \tag{7}$$

Duncan (1958) showed a linear relationship between the logarithm of average plant yield and the corn population, expressed as

$$y = k10^{-bx} \tag{8}$$

where k and b are constants. With different emphasis from that of Shinozaki and Kira (1956), Holliday (1960a, 1960b) observed a linear relationship between the reciprocal of yield per plant (rape, kale, potatoes, and perennial ryegrass) and density. The mathematical expression is similar to that in Eq. (6) as proposed by Shinozaki and Kira (1956). In order to make the equation functional at the density where competition first starts, he modified the equation which he

expressed as

$$\frac{1}{y} = a' + bm \tag{9}$$

where $m = x - n$, i.e., n = density where the competition first starts; a' and b are constants where $1/a'$ is the true maximum yield per plant for density less than n. Holliday (1960c) further suggested that in situations where a parabolic relationship between yield per unit area and density is present, the relationship between the reciprocal of yield per plant and density is expressed in quadratic form as

$$\frac{1}{y} = a + bx + cx^2 \tag{10}$$

where a, b and c are regression constants. Based on a generalization of the logistic growth curve, Bleasdale and Nelder (1960) proposed a reciprocal equation of yield per plant versus density as

$$\frac{1}{y^\theta} = a + bx^\theta \tag{11}$$

where θ, a and b are constants. Equation (11) will produce asymptotic yield per unit area vs. density relationship, whereas if the power on x is greater than that on y, then the parabolic situation of yield per unit area vs. density results. Thus, Eq. (11) is reexpressed as

$$\frac{1}{y^\theta} = a + bx^\phi \tag{12}$$

where ϕ is a constant. However, for practical reasons and since the ratio of θ and ϕ is more important than their values (Bleasdale and Thompson, 1966), ϕ may be taken as unity, and Eq. (12) can be

rewritten as

$$\frac{1}{y^{\theta}} = a + bx \qquad (13)$$

Warren (1963) proposed a linear relationship between yield per plant of sweetcorn and density, expressed as

$$y = a - bx \qquad (14)$$

where a and b are the intercept and slope of the regression line obtained, respectively. Carmer and Jackobs (1965) suggested an equation that is basically similar to the model as proposed in Eq. (8) by Duncan (1958). They presented the equation as

$$y = AK^{x} \qquad (15)$$

where the product AK represents the yield when there is only one plant per unit area (x = 1). Relating Eq. (15) to Eq. (8), K becomes 10^{-b}. If natural logarithm is imposed in producing Eq. (8), then $K = e^{-b}$.

Farazdaghi and Harris (1968) proposed an equation that is similar to that suggested by Shinozaki and Kira (1956), except they indicated that the law of constant final yield for crop TDM which had been considered by the latter workers may not always be true. Thus the derived equation can be expressed as

$$\frac{1}{y} = a + bx^{\alpha} \qquad (16)$$

where if $\alpha = 1$, then the relationship between yield per area and density will be asymptotic, and if $\alpha < 1$, then the above relationship

will be parabolic. If a = 0, then Eq. (16) simplifies to the form of Eq. (5).

Duncan (1984) used the concept of competition which he hypothesized to consist of two components, i.e., crowding (C) (dimensionless) and the effect of crowding (E) on grain yield, in explaining the relationship between corn population and grain yield. Crowding is calculated as

$$C = \sum_{p=1}^{p=n} SF^{ALPHA}$$

where SF = separation fraction = (DMAX - Separation)/DMAX,

Separation = distance between target plant and surrounding plant,

DMAX = maximum separation where C becomes first measurable,

p=1...p=n = includes all plants in the planting pattern within the distance DMAX of a chosen center plant,

ALPHA = value that controls the rate of change in the value of C with separation, and the value of ALPHA is related to the value chosen for DMAX.

Duncan (1984) proposed that the yield reduction per plant for each increase in crowding is a fixed fraction of yield per plant, expressed as

$$\frac{dy}{dC} = Ey. \qquad (17)$$

Integration yields

$$y = y_o e^{EC} \tag{18}$$

where y_o is the yield of a single corn plant at zero crowding (competition free), and E is a negative constant which has the value of natural log of the yield factor at one unit crowding.

It was shown that Eqs. (6), (9) and (16) are based on a generalized law of constant final yield or related to the logistic growth curve which normally relates yield to time or age. Some constant power exponents which normally are based on allometry are included and depending on the power of this exponent, the resulting yield per area vs. density relationship will either be asymptotic or parabolic. Equations (1) and (18) were developed based on direct physiological relationships, i.e., change in yield per plant with respect to (a) supply of growth factor that is proportional to that potentially available [Eq. (1)], and (b) crowding that is proportional to the yield [Eq. (18)]. The majority of the other equations were empirically developed and based on either asymptotic or parabolic relationships between yield per area and density. For example, several equations were empirically obtained from the observed linear relationships of response per plant vs. density, logarithm of response per plant vs. density, reciprocal of response per plant vs. density, and logarithm of response per plant vs. logarithm of space available per plant (i.e., logarithm of reciprocal density).

Duncan (1984), with Eq. (18), presented some direct physiological reasoning in the relationship between yield per plant of corn and density. However, Duncan's crowding concept was only tested on

corn data. As mentioned earlier, C was calculated based on SF raised to the power of ALPHA which controls the rate of change in C. It is then difficult to directly relate plant density effect to yield. Some concepts of DMAX and C [Eq. (18)] from Duncan (1984), and the concept of the smallest density that first gives competition as proposed by Holliday (1960a) and indicated by Duncan (1958), will be used as partial requisites in developing the model proposed here, which relates reduction in response per plant to density of peanut or sweetcorn under a specific environment.

The proposed model has two features that do not appear in most of the other models. First, the model is designed to allow an apparent residual response per plant at high plant population densities. This feature was desired to match observations of experimental data obtained from crops on the Malaysian histosol. Second, the model separates crop responses into two population density regions, namely a noncompetitive, low-density region where plant response is unaffected by density (constant response), and a competitive region where response per plant decreases with increasing density and approaches asymptotically an apparent residual response per plant. The proposed model is formulated as a response (yield) per plant vs. density expanded to a response (yield) per unit land area vs. density.

In developing the model, it was necessary to define a critical population density to separate the competition-free densities from the densities where competition becomes the governing factor in determining response per plant. The label given to the maximum land

area per plant where competition ceases was $DMAX^2$. This concept is similar to Duncan (1984), except in practical use of the model, row spacing was held fixed so that plant spacing in the row was the only variable affecting computations of plants per $DMAX^2$.

It is postulated that the reduction in the response per plant (y) with respect to change (increase) in competitive density (x_c) is proportional to the net response ($y - y_{ar}$) at that density (defined as the competition or physiological relationship) and expressed as

$$\frac{dy}{dx_c} = -K(y - y_{ar}) \qquad ; x_c \geq 0 \qquad (19)$$

Integration yields

$$y = y_{ar} + (y_o - y_{ar})e^{-Kx_c} \qquad ; x_c \geq 0 \qquad (20)$$

Substituting $\frac{1}{x_c} = K$ and $x_c = x - 1$ into Eq. (20) yields

$$y = y_{ar} + (y_o - y_{ar})e^{\frac{-(x-1)}{x_c}} \qquad ; x \geq 1 \qquad (21)$$

where y_{ar} = apparent residual response per plant at high density;

y_o = response per plant at intraspecific competition-free conditions, i.e., at a threshold low density where competition ceases to be a factor that affects response per plant;

$x_c = x - 1$ = competitive density (number of competitive plants per $DMAX^2$), where x is the actual density in plants per $DMAX^2$, $DMAX^2$ is the threshold competitive area,

and the DMAX is distance between two plants where competition first starts;

X_c = competitive density constant.

The above variables and parameters (constants) have their own biological and physical meanings. The y_{ar} is minimum response (yield) per plant that apparently is further undifferentiable even under high plant density with a given genotype and environment.

As previously discussed, Duncan (1958) used $y = K10^{-bx}$ in relating corn grain yield per plant with density, which showed that the logarithm of yield per plant was linearly related to plant density. However, he indicated that the relationship was true for densities ranging from 14,826 to 61,775 plants ha^{-1}, but the deviation from this linearity would occur with higher plant density. The deviation was clearly observed from data reported by Haynes and Sayre (1956), where density was as high as 148,200 plants ha^{-1}. The above trend was also indicated by Fery and Janick (1971). The density range restriction was also applied to a recently developed model of Duncan (1984). It is felt, therefore, that deviation from the log (yield per plant) vs. density linear relationship is due to the presence of "apparent constant average yield per plant" with increasing density. This situation is similar to yield per plant below the density at which population or density pressure is no longer the yield-limiting factor (Duncan, 1958; Holliday, 1960a). Below this density, the yield per plant is constant since no competition from neighboring plants is experienced, and apparently the density reported by Duncan (1958) was

14,826 plants ha^{-1}. Referring back to the higher density situation, even if some barren stalks (might bear ears but without grain) are present at high density, some kind of balancing between barren and bearing stalk plants will prevail, resulting in apparent average constant yield per plant. The density is referred to as the surviving plants until maturity per unit area, rather than seeding rate. Bleasdale (1967) indicated that self-thinning would occur with initially high planting density. However, if marketable ear in sweetcorn (ear with some standard measurement criteria) is the yield, then yield per plant is probably zero at high density, but it is not zero for the total reproductive (ear) yield per plant. In alfalfa, Volenec et al. (1987) used a regression model of $y = a - bx + cx^2$ in relating shoot per plant or yield per shoot of three cultivars with density (11 to 172 plants m^{-2}). With this model, they showed that the shoot per plant or yield per shoot at high density "leveled off," but apparently increased a little at 172 alfalfa plants m^{-2}.

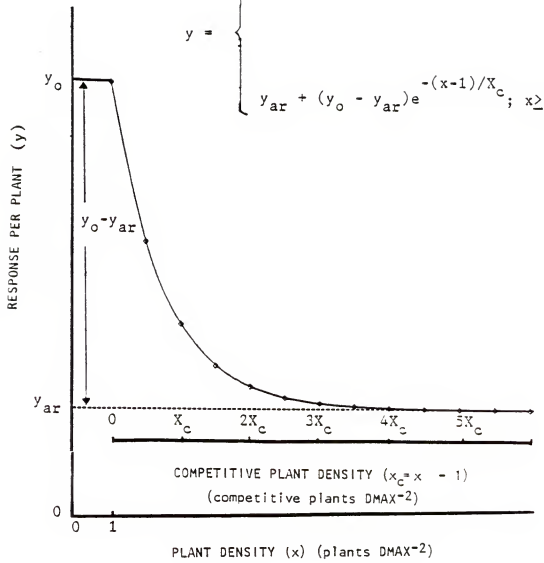
Competitive plant density, x_c (or $x - 1$), is the number of plants per $DMAX^2$ that are competitive for growth limiting factors. If only one plant is present in an area of $DMAX^2$ (where interrow = intrarow = DMAX), the plant does not experience competition and thus $x_c = 0$. Competition starts when there are more than one plant per $DMAX^2$. However, in practice, square planting in crop plants is seldom used, and thus with constant reasonable interrow spacing, very minimum or negligible competition effect is assumed for plants at 1 plant per $DMAX^2$ (where interrow x intrarow = $DMAX^2$). In this manner, x_c can generally be regarded as "crowding" for each type of crop plant.

Various crop plants will behave differently when grown at higher densities and thus they will have different values of DMAX. The X_c [Eq. (21)] will indicate the level of competitive plant density that reduces response per plant to $y_{ar} + (y_o - y_{ar})e^{-1}$ or $y_{ar} + (y_o - y_{ar})$ x 37%. The X_c is analogous to the time constant in negative exponential time decay formulations. Therefore, the X_c could be used as a measure of "speed" of response, that is, the number of plants required to reduce response per plant to 37% of its reducible portion per plant. Since response per plant will be constant when $-1 < x_c \leq 0$ (or $0 < x \leq 1$), Eq. (21) can be rewritten more functionally as shown in Figure 1. Equation (22) (Figure 1) will cover more realistically densities (x) ranging from a value slightly above 0 to that specified by the researcher. The curve in Figure 1 will cease to have practical meaning at a point that corresponds to the highest surviving plant density. The estimates of y_o, y_{ar} and X_c were obtained from PROC NLIN solution (SAS, 1985), i.e., from nonlinear regression of yield (response) per ha vs. density. The model used was $Y = y_{ar}C(x_c + 1) + BC(x_c + 1)e^{-Dx_c}$, where $B = y_o - y_{ar}$ and $D = 1/X_c$. The C is a conversion factor of g $DMAX^{-2}$ into kg ha^{-1}. The resulting estimates produced better fit of yield per plant vs. density relationship compared to the estimates obtained from regression of yield per plant vs. density ($y = y_{ar} + Be^{-Dx_c}$).

Per unit area basis. Hudson (1941) proposed a quadratic equation in describing the relationship between grain yield per unit area (Y) and seeding rate (x) of winter wheat as

Figure 1. Schematic illustration of theoretical response per plant as affected by plant density. The y_o, y_{ar}, X_c, and $DMAX^2$ are the response per plant at intraspecific competition free, apparent residual per plant, competitive density constant, and threshold competitive area, respectively. Competitive plant density is indicated by $x_c = x - 1$.

$$y = \begin{cases} y_o & ; 0 < x \leq 1 \\ y_{ar} + (y_o - y_{ar})e^{-(x-1)/X_c} & ; x \geq 1 \end{cases} \qquad (22)$$



$$Y = a + bx + cx^2 \tag{23}$$

where a, b, and c (negative) are constants. Response per unit area basically can be calculated as

$$Y = yx \tag{24}$$

where y and x are response per plant and planting density, respectively. Using Eqs. (24) and (14), Warren (1963) calculated yield per unit area with an equation similar to Eq. (23), but with zero intercept (a = 0). In order to avoid the symmetrical nature of the quadratic curve, Sharpe and Dent (1968) proposed an equation that included a square root term which can be expressed as

$$Y = a + bx + cx^{0.5} \tag{25}$$

where a, b (negative) and c are constants. The above quadratic equations [Eq. (23), with either zero or nonzero intercept, and Eq. (25)] should not be used if the data are lacking in biological validity, for example, the usage of few data in describing the response in quadratic form, and also should not be used for extrapolation purposes (Willey and Heath, 1970).

To make a group of reciprocal equations to be functional in relating yield per area and density, each of Eqs. (6), (9), (10), (12), (13) and (16) should be substituted into Eq. (24), and the generalized resulting equation (not including some power constants) can be expressed as

$$Y = \frac{x}{a + bx} \tag{26}$$

If it involves a quadratic term as suggested by Holliday (1960c), the equation is expressed as

$$Y = \frac{x}{a + bx + cx^2} \tag{27}$$

In Eqs. (26) and (27), a, b, and c are constants which are obtained from the relationship between reciprocal of yield per plant and density. De Wit and Ennik (1958) proposed an equation which directly relates the reciprocal of yield per unit area and row width (d_2) at constant intrarow spacing. The equation can be expressed as

$$\frac{1}{Y} = a + bd_2 \tag{28}$$

where a and b are constants. Later, de Wit (1960) suggested an equation that was based on the linear relationship beween the reciprocal of yield per area and space available per plant(s). This equation can be expressed as

$$\frac{1}{Y} = \frac{1}{P} + \frac{s}{PQ} \tag{29}$$

or

$$Y = \frac{PQ}{Q + s}$$

where 1/P and Q are the intercepts on 1/y and s axes, respectively; and P is the asymptote of Y when s approaches zero, or equivalently when density approaches infinity.

In the exponential model, each of Eqs. (8), (15) and (18) need to be substituted into Eq. (24) in deriving equations relating yield per area and density. The equation from Duncan (1958) can be expressed as

$$Y = xa10^{-bx} \tag{30}$$

where a and b are constants derived from Eq. (8). The equation from Carmer and Jackobs (1965) can be written as

$$Y = xAK^{x} \tag{31}$$

where A and K are constants derived from Eq. (14). Likewise, the equation that relates yield per area and crowding (which related to plant density) as developed from yield per plant by Duncan (1984) can be expressed as

$$Y = xy_{o}e^{EC} \tag{32}$$

where x is density, and y_o, E and C are as defined in Eq. (18). In a similar approach, Eq. (22) (Figure 1) which is proposed in this study was substituted into Eq. (24) which yields Eq. (33) relating response per unit area ($DMAX^2$) to density, which mathematically can be expressed as

$$Y = \begin{cases} y_{o}x & ; \ 0 < x \leq 1 \\ y_{ar}x + (y_{o} - y_{ar})xe^{-\frac{(x-1)}{X_c}} & ; \ x \geq 1 \end{cases} \tag{33}$$

where y_{ar}, y_o and X_c are as defined in Eq. (22). In Eq. (33), Y will be linearly related to density if $0 < x \leq 1$. The nature of the response curve [Eq. (33)] for $x \geq 1$ can be determined by inspection which includes a reasonable set of assumptions about y_{ar}, y_o, X_c, and DRR. The DRR is the differentiable response ratio and defined as $(y_o - y_{ar})/y_{ar}$. The assumptions are (a) $(y_o - y_{ar}) > y_{ar}$, then

$(y_o - y_{ar})/y_{ar} > 1$ and (b) $X_c > 1$ (it has to be). The nature of the curve tends to be linear at larger values of x, i.e., at $x >> X_c$, because the exponential term will tend toward zero, and hence the slope will approach y_{ar}. At low values of x, i.e., $(x-1) << X_c$, the curve will tend to be parabolic. Between the parabolic and linear regions, Eq. (33) can produce a broad, flat "asymptotic" zone depending on the values of the parameters. The details of the above situation are

(a) Small X_c causes a "rapid" increase in the argument of the exponential function as x increases. Since the argument of the exponential factor carries a negative sign, the exponential function becomes small "rapidly." Therefore, the first term (linear) becomes dominant "rapidly" with increase in x, especially if DRR is relatively small. However, if DRR is relatively large, the equation produces a curve segment that is dominated by the contributions from $(y_o - y_{ar})xe^{-(x-1)/X_c}$ which tends to be parabolic,

(b) Large X_c causes a "slow" increase in the absolute magnitude of the argument in exponential function of Eq. (33) as x increases. Since the argument carries a negative sign, the exponential function becomes small "slowly." Therefore, if DRR value is in a certain range, usually moderately small, Eq. (33) can produce a relatively flat curve ("asymptotic") across a broad range of plant densities. This behavior would describe the "law of constant final yield" situation (Shinozaki and Kira, 1956).

If response per unit of larger area is required (for example in kg ha^{-1}), then the factor for converting yield per $DMAX^2$ into per ha should be used.

Results and Discussion

General

The data were analyzed for each cycle of experimentation for two reasons: (a) some cycle x treatment (N, cropping system, or plant density) interactions were present, and (b) more importantly, the consistencies of the proposed mathematical models relating responses (per plant and per ha) with plant density in different environments (N x cropping system) and cycles could be tested and verified. There was some lodging of corn (7%) in cycle 2 due to wind at 47 days after planting. A support system (stake arrangement that did not affect understory peanut growth) was immediately erected. The corn growth and yields appeared to be normal. The plant counts of sweetcorn and peanut at harvest were consistent with the initially respective assigned densities. Evans and Sreedharan (1962) found that intercrop castor bean had no effect on plant densities of peanut and soybean. Similarly, Searle et al. (1981) reported that N fertilization and intercrop maize had no effect on peanut or soybean densities.

Based on the height of corn in single-plant plots, the corn cv. 'Thaisupersweet' distance at negligible competition or CDMAX (Duncan, 1984) was estimated at 1.8 m. The reported height of the above cultivar grown under Malaysian environment was 1.7 m (Lee et al., 1983). Based on the mature height of usual Corn Belt cultivars,

Duncan (1984) estimated CDMAX as 3.0 m. Based on the maximum circumference of peanut grown in single-plant plots which exceeded height, the peanut cv. 'Matjam" distance at negligible competition or PDMAX was estimated at about 1.0 m.

Peanut Total Dry Matter Per Plant

Table 4 shows that the main effects, nitrogen (N) (except in cycle 3), system-corn density (S-C), and peanut density (P), had significantly greater influence on the peanut total dry matter (TDM) yield per plant as compared to their interactions. In all three cycles, P was the most dominant factor in influencing TDM per plant. However, some degree of interaction among sources [N x P (cycles 1 and 2) and P x S-C (cycles 1, 2, and 3)] were indicated, but with relatively small F values (Table 4).

The average TDM yields per plant in N-fertilized plots (150 kg N ha^{-1}) of all cycles were higher than those in the non-N-fertilized plots (Table 4). Nodulation in peanut grown on peat soil was observed to be low, even with high liming (Shamshuddin, 1984). Thus N fertilization was necessary for individual peanut plant growth. Figure 2 and Appendix Table B-1 show that the N-fertilized monocropping plots of peanut planted at the relayplanting date [monocropping-(R)] (N applied at intercrop planting time) for cycle 1 had lower TDM yields per plant compared to the monocropping plots planted earlier at the interplanting date [monocropping-(I)]. The above trend was also observed for TDM yields in non-N-fertilized plots of cycle 1. Similar trends were found in cycles 2 and 3 (Figures 3 and 4; Appendix Table B-1). These results suggest (a) some N loss

Table 4. Peanut total dry matter (TDM) and pod yield per plant as affected by nitrogen rate, system-corn density, and peanut density in three cycles of experimentation on a Malaysian histosol.

Treatment†	Total dry matter			Pod yield		
	Cycle			Cycle		
	1	2	3	1	2	3
	g plant^{-1}					
Nitrogen (N)						
0 kg ha^{-1}	10.8	10.5	10.8	4.3	3.8	4.2
150 kg ha^{-1}	18.8	16.2	13.1	7.4	5.8	4.7
LSD (0.05)	7.3	2.6	2.2	2.2	1.4	0.5
System-corn density (S-C)						
Intercropping at 2.7 plants m^{-2}	21.3	17.4	12.9	7.1	6.5	4.7
Intercropping at 5.3 plants m^{-2}	14.2	14.7	10.6	6.1	5.8	3.6
Intercropping at 13.3 plants m^{-2}	15.0	11.6	8.7	4.8	3.8	2.5
Relaycropping at 2.7 plants m^{-2}	7.8	6.3	8.5	2.9	2.0	3.7
Relaycropping at 5.3 plants m^{-2}	9.9	7.1	7.6	4.2	2.1	3.4
Relaycropping at 13.3 plants m^{-2}	8.5	5.6	10.7	3.7	1.7	3.8
Monocropping-(I)	28.3	30.8	23.9	12.2	11.6	8.2
Monocropping-(R)	13.3	13.5	13.0	5.8	4.7	5.8
LSD (0.05)	5.5	3.5	3.4	2.5	1.8	1.4
Peanut density (P)						
5 plants m^{-2}	27.2	23.6	21.0	11.6	9.7	8.8
10 plants m^{-2}	18.5	17.6	15.5	7.8	6.4	5.8

20 plants m^{-2}	13.0	12.0	9.9	4.8	3.8	3.5
40 plants m^{-2}	8.9	8.4	7.2	3.1	2.5	2.4
80 plants m^{-2}	6.3	5.4	6.2	2.0	1.6	1.8
LSD (0.05)	3.0	2.0	1.8	1.5	1.0	0.7
			F Statistics (F value)			
N	10.83*	41.92**	9.07^{+}	17.11*	15.57*	8.42^{+}
S-C	12.40**	43.88**	17.20**	10.75**	28.18**	12.62**
P	55.11**	95.52**	85.89**	50.43**	82.33**	129.1**
N x S-C	2.10^{+}	1.87^{+}	1.20^{ns}	1.38^{ns}	1.51^{ns}	1.08^{ns}
N x P	3.89**	3.87**	1.23^{ns}	5.01**	2.17^{+}	0.57^{ns}
S-C x P	3.12**	6.89**	4.59**	2.78**	6.01**	5.43**
N x S-C x P	0.55^{ns}	0.38^{ns}	0.43^{ns}	0.63^{ns}	0.18^{ns}	0.71^{ns}

†: N, S-C, and P were as main-, sub-, sub-sub-plots, respectively.

+, *, **: significant at $\alpha = 0.10$, $\alpha = 0.05$, and $\alpha = 0.01$ levels, respectively.

ns: not significant at $\alpha = 0.10$ level.

Figure 2. Relationships between peanut total dry matter per plant and plant density in mono-, inter-, and relaycropping environments of Cycle 1 experimentation on a Malaysian histosol. Monocropping-(I) and monocropping-(R) indicate monocroppings that correspond to inter- and relayplanting dates, respectively. Response trends in inter- and relaycropping represent over three sweetcorn densities. $PDMAX^2 = 1.0\ m^2$. The LSD bar shown is for comparison between two system-corn density (cropping system at each corn density) yields at same nitrogen x peanut density combination. The respective values of effects and LSD bar shown are indicated in Appendix Table B-1.

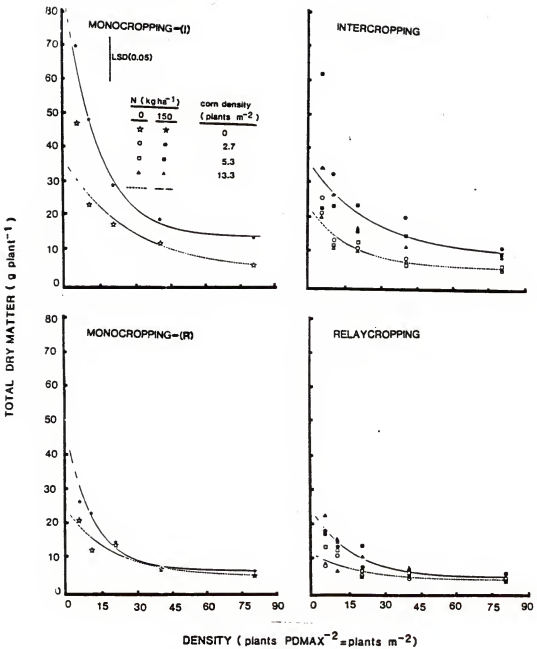

MONOCROPPING-(I)
LSD(0.05)
N (kg ha⁻¹)
0
150
corn density
(plants m⁻²)
0
2.7
5.3
13.3
INTERCROPPING
MONOCROPPING-(R)
RELAYCROPPING
TOTAL DRY MATTER (g plant⁻¹)
DENSITY (plants PDMAX⁻²=plants m⁻²)
0
10
20
30
40
50
60
70
80
0
15
30
45
60
75
90

Figure 3. Relationships between peanut total dry matter per plant and plant density in mono-, inter-, and relaycropping environments of Cycle 2 experimentation on a Malaysian histosol. Monocropping-(I) and monocropping-(R) indicate monocroppings that correspond to inter- and relayplanting dates, respectively. Response trends in inter- and relaycropping represent over three sweetcorn densities. $PDMAX^2$ = 1.0 m^2. The LSD bar shown is for comparison between two system-corn density (cropping system at each corn density) yields at same nitrogen x peanut density combination. The respective values of effects and LSD bar shown are indicated in Appendix Table B-1.

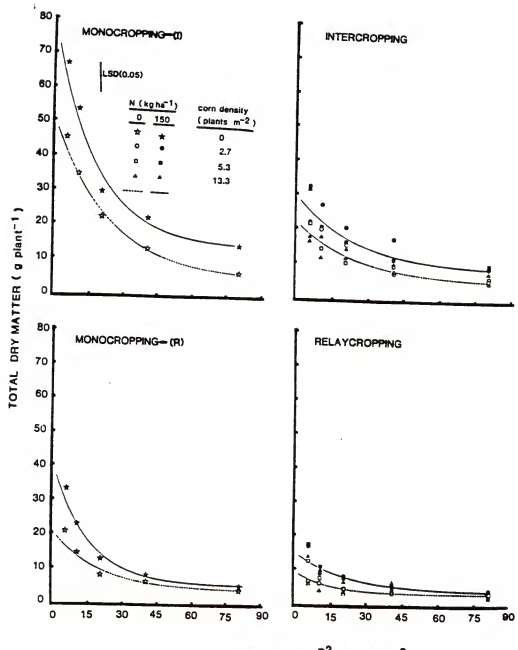
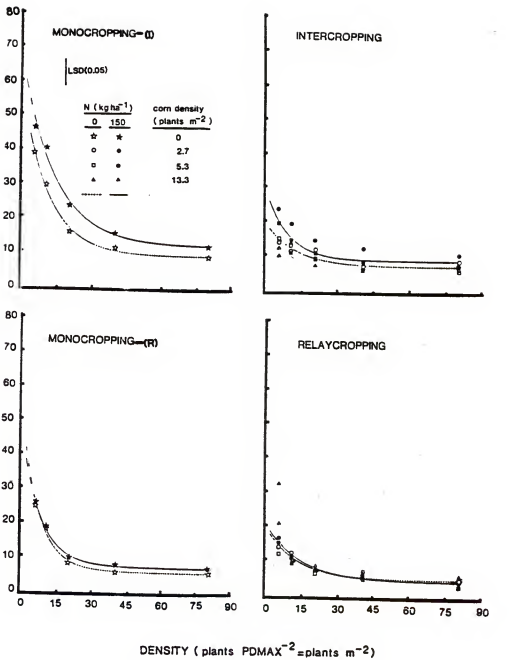

MONOCROPPING—(I)
INTERCROPPING
MONOCROPPING—(R)
RELAYCROPPING
LSD(0.05)
N (kg ha⁻¹)
0
150
corn density
(plants m⁻²)
0
2.7
5.3
13.3
TOTAL DRY MATTER (g plant⁻¹)
DENSITY (plants PDMAX⁻²=plants m⁻²)
0
10
20
30
40
50
60
70
80
0
15
30
45
60
75
90

Figure 4. Relationships between peanut total dry matter per plant and plant density in mono-, inter-, and relaycropping environments of Cycle 3 experimentation on a Malaysian histosol. Monocropping-(I) and monocropping-(R) indicate monocroppings that correspond to inter- and relayplanting dates, respectively. Response trends in inter- and relaycropping represent over three sweetcorn densities. $PDMAX^2 = 1.0\ m^2$. The LSD bar shown is for comparison between two system-corn density (cropping system at each corn density) yields at same nitrogen x peanut density combination. The respective values of effects and LSD bar shown are indicated in Appendix Table B-1.


MONOCROPPING-(I)
LSD(0.05)
N (kg ha⁻¹)
0 150
corn density
(plants m⁻²)
0
2.7
5.3
13.3
INTERCROPPING
MONOCROPPING-(R)
RELAYCROPPING
TOTAL DRY MATTER (g plant⁻¹)
DENSITY (plants PDMAX⁻²=plants m⁻²)
0 15 30 45 60 75 90
0 10 20 30 40 50 60 70 80

from applied urea on this peat soil (Volk, 1959; Ng and Tay, 1973), and probable N fixation due to high C:N ratio, and (b) probable immobilization (due to organic complex) of non-N nutrients during inter- and relayplanting periods, where available phosphorus, potassium, magnesium and micronutrients (especially copper) are low in the Malaysian peat (Joseph et al., 1974). Thus, the reduced peanut plant size in relaycropping (Figures 2, 3, and 4) was probably mainly due to low N and other nutrients at relayplanting time and, therefore, only a small proportion of the reduction appeared to be due to limiting light. Furthermore, Figures 2, 3, and 4 show that the N effects at various corn densities were less pronounced (especially in cycle 3) in peanut TDM yields per plant between relaycropping plots receiving 0 and 150 kg N ha^{-1} compared to those in intercropping. This reveals that the N status in N-treated plots during the peanut relaycropping period was only slightly better than that in non-N-fertilized and caused greater competition for soil N at higher densities.

Table 4 shows that TDM per peanut plant of monocropping-(I) in cycle 1 was higher than those of intercroppings (at three corn densities) and of relaycroppings. Furthermore, the differences in individual peanut growth at three corn densities were more pronounced at lower peanut densities (5 and 10 plant m^{-2}) (Figure 2 and Appendix Table B-1). The peanut TDM yields per plant at 2.7 corn plants m^{-2} were consistently higher than those at 5.3 and 13.3 plants m^{-2} among five peanut densities in N-fertilized intercropping environments of cycles 1. The above trends, but with some less consistencies and with

little effects due to corn densities, were also observed in the non-N-fertilized plots. More inconsistent corn density effects were observed in N- and non-N-fertilized relaycroppings. All the above trends were also shown in cycles 2 and 3 (Figures 3 and 4; Appendix Table B-1). The above findings suggest that the corn presence and density were important in reducing individual peanut plant size in N-fertilized intercropping system, whereas only corn presence was apparently important in the non-N-fertilized intercropping, and in the relaycropping regardless of N treatments.

The peanut TDM per plant decreased sharply with increasing peanut density in all cycles and in all environments (N x C-S) (Table 4; Figures 2, 3, and 4; Appendix Table B-1). The trend indicates greater competition (smaller plant size) for growth limiting factors at higher plant density which agrees with results reported on corn by Duncan (1984). Despite the treatments employed in this study, peanut density was still an important factor affecting individual peanut plant growth in the Malaysian histosol environment.

Pod Yield Per Plant

The pod yield per plant was greatly affected by main effects of N, S-C, and P (Table 4). The trends of various P effects at each N x S-C combination on the peanut pod yield per plant were similar to those of previously discussed TDM yield per plant (Figures 5, 6, and 7; Appendix Table B-1). The discussion describing TDM per plant as affected by treatments employed is therefore also similarly applicable in describing pod yield per plant. Duncan (1986) postulated that when

Figure 5. Relationships between peanut pod yield per plant and plant density in mono-, inter-, and relaycropping environments of Cycle 1 experimentation on a Malaysian histosol. Monocropping-(I) and monocropping-(R) indicate monocroppings that correspond to inter- and relayplanting dates, respectively. Response trends in inter- and relaycropping represent over three sweetcorn densities. $PDMAX^2 = 1.0\ m^2$. The LSD bar shown is for comparison between two system-corn density (cropping system at each corn density) yields at same nitrogen x peanut density combination. The respective values of effects and LSD bar shown are indicated in Appendix Table B-1.

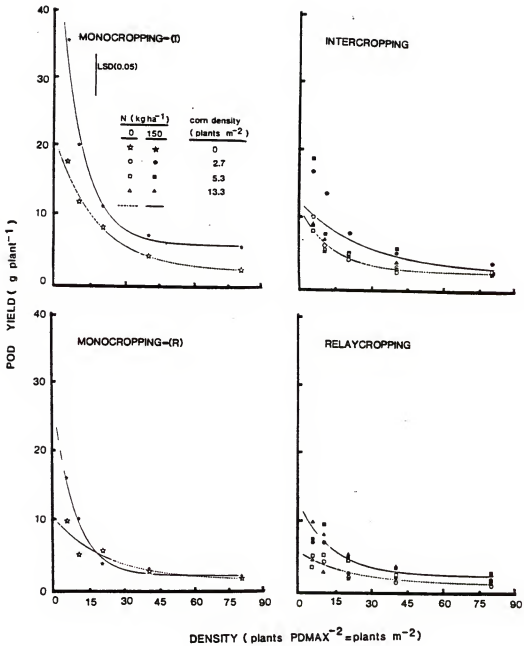

MONOCROPPING=(I)
LSD(0.05)
N (kg ha⁻¹)
0
150
corn density
(plants m⁻²)
0
2.7
5.3
13.3
INTERCROPPING
MONOCROPPING=(R)
RELAYCROPPING
POD YIELD (g plant⁻¹)
DENSITY (plants PDMAX⁻² =plants m⁻²)
0
10
20
30
40
0
15
30
45
60
75
90

Figure 6. Relationships between peanut pod yield per plant and plant density in mono-, inter-, and relaycropping environments of Cycle 2 experimentation on a Malaysian histosol. Monocropping-(I) and monocropping-(R) indicate monocroppings that correspond to inter- and relayplanting dates, respectively. Response trends in inter- and relaycropping represent over three sweetcorn densities. $PDMAX^2 = 1.0\ m^2$. The LSD bar shown is for comparison between two system-corn density (cropping system at each corn density) yields at same nitrogen x peanut density combination. The respective values of effects and LSD bar shown are indicated in Appendix Table B-1.

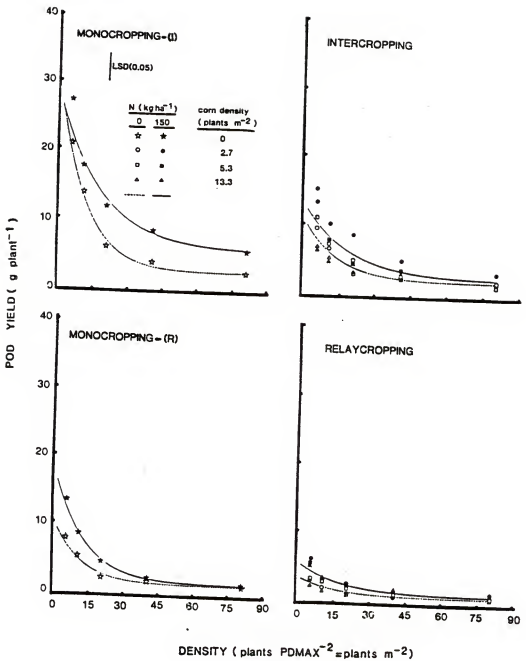
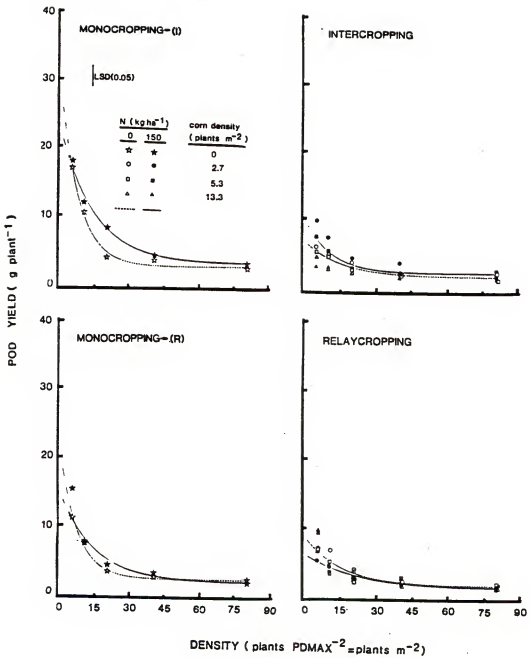

MONOCROPPING-(I)
LSD(0.05)
N (kg ha⁻¹)
0
150
corn density
(plants m⁻²)
0
2.7
5.3
13.3
INTERCROPPING
MONOCROPPING-(R)
RELAYCROPPING
POD YIELD (g plant⁻¹)
DENSITY (plants PDMAX⁻²=plants m⁻²)
0
10
20
30
40
0
15
30
45
60
75
90

Figure 7. Relationships between peanut pod yield per plant and plant density in mono-, inter-, and relaycropping environments of Cycle 3 experimentation on a Malaysian histosol. Monocropping-(I) and monocropping-(R) indicate monocroppings that correspond to inter- and relayplanting dates, respectively. Response trends in inter- and relaycropping represent over three sweetcorn densities. $PDMAX^2 = 1.0\ m^2$. The LSD bar shown is for comparison between two system-corn density (cropping system at each corn density) yields at same nitrogen x peanut density combination. The respective values of effects and LSD bar shown are indicated in Appendix Table B-1.


MONOCROPPING-(I)
INTERCROPPING
MONOCROPPING-(R)
RELAYCROPPING
LSD(0.05)
N (kg ha⁻¹)
0
150
corn density
(plants m⁻²)
0
2.7
5.3
13.3
POD YIELD (g plant⁻¹)
DENSITY (plants PDMAX⁻²=plants m⁻²)
0
10
20
30
40
0
15
30
45
60
75
90

all other conditions remain the same, soybean yield is directly related to vegetative plant weight.

In cycle 1, the pod yields per plant in the N-fertilized monocropping-(I) at the densities from 5 to 80 peanut plants m^{-2} were nearly 2-fold of those from comparable densities in intercropping plots (Figure 5; Appendix Table B-1). Generally, in the above intercropping, peanut pod yield per plant decreased with increasing corn plant density (Figure 5). The corresponding pod yields at non-N-fertilized monocropping-(I) were similar to those of N-fertilized intercropping (Figure 5; Appendix Table B-1). Similar trends were found in cycles 2 and 3 (Figures 6 and 7; Appendix Table B-1). In a study on an Alfisol, Nambiar et al. (1983) reported that the peanut pod yield per plant of peanut monoculture (26.7 plants m^{-2}) and peanut intercropped in maize (13.3 and 6 plants m^{-2} of peanut and maize, respectively) without N-fertilization were 3.9 and 3.1 g $plant^{-1}$, respectively. They further indicated that the values of intercropping plots with 50, 100, and 150 kg N ha^{-1} were 2.4, 2.4, and 2.1 g $plant^{-1}$, respectively. They reasoned that reduced plant size was related to decreased nodulation as a consequence of low peanut photosynthesis due to denser canopies of shade-crop maize with increased N fertilization. Furthermore, the N-fertilized intercrop pod yields per plant were generally consistently higher in 2.7 corn plants m^{-2} compared to those at 5.3 and 13.3 plants m^{-2} in all three cycles (Figures 5, 6, and 7), which indicates that low light was an

additive factor to low N in reducing pod yield in intercropping treatment. The generally slightly higher pod yields per plant in N-fertilized monocropping-(R) vs. relaycropping plots, especially at lower peanut densities (5 to 10 plants m^{-2}), and with some inconsistency effects of corn densities (2.7 to 13.3 plants m^{-2}) in relaycropping plots, suggest that reduced availability of nutrients (especially N) and probably minimal shading by corn were the reasons for lower relaycrop peanut yield per plant. Due to quite close effects of N vs. non-N fertilization on peanut growth and yield, nodulation might have a measurable effect in the non-N-fertilized treatment of cycle 3.

Peanut Total Dry Matter and Pod Yield Per Plant Models

Table 5 shows the equations relating peanut TDM or pod yields per plant with peanut densities (1 to 80 plants $PDMAX^{-2}$ = plants m^{-2}), whereas their response trends at each specified environment at three cycles are shown in Figures 2 to 7. The parameter estimates of apparent residual (y_{ar}), response at intraspecific competition free (y_o), and peanut competitive density constant (X_{cp}) are presented in Table 6.

In studies of per plant response (TDM or pod yield) with density, most workers found a certain measurable yield per plant at the highest density tested. The calculated peanut pod or seed yields per plant at respective highest plant densities under monoculture environment obtained by several workers were 0.8 to 1.2 g seed $plant^{-1}$

Table 5. Equations[†] of peanut total dry matter (TDM) and pod yield per plant (y) against peanut density (x) for $1 \leq x < 80$ plants $PDMAX^{-2}$ under nitrogen x cropping system environments in three cycles of experimentation on a Malaysian histosol.

Cropping system	Nitrogen (kg ha^{-1})	TDM $plant^{-1}$	Pod yield $plant^{-1}$
		Cycle 1	
Intercropping[°]	0	$y = 5.52 + 15.70e^{-(x-1)/16.59}$	$y = 2.02 + 8.06e^{-(x-1)/13.61}$
Monocropping-(I)[¶]	0	$y = 3.65 + 30.59e^{-(x-1)/27.72}$	$y = 1.85 + 17.44e^{-(x-1)/17.88}$
Relaycropping[°]	0	$y = 3.28 + 7.55e^{-(x-1)/20.42}$	$y = 0.80 + 4.03e^{-(x-1)/20.12}$
Monocropping-(R)[#]	0	$y = 4.63 + 17.64e^{-(x-1)/19.39}$	$y = 1.03 + 8.56e^{-(x-1)/22.37}$
Intercropping	150	$y = 9.21 + 24.85e^{-(x-1)/25.73}$	$y = 2.14 + 9.37e^{-(x-1)/27.13}$
Monocropping-(I)	150	$y = 13.48 + 67.15e^{-(x-1)/13.85}$	$y = 5.55 + 39.82e^{-(x-1)/9.87}$
Relaycropping	150	$y = 4.06 + 18.41e^{-(x-1)/17.25}$	$y = 1.95 + 9.18e^{-(x-1)/13.93}$
Monocropping-(R)	150	$y = 6.23 + 34.73e^{-(x-1)/11.51}$	$y = 1.72 + 21.68e^{-(x-1)/8.96}$
		Cycle 2	
Intercropping	0	$y = 4.25 + 16.43e^{-(x-1)/24.93}$	$y = 1.78 + 8.19e^{-(x-1)/13.90}$
Monocropping-(I)	0	$y = 4.42 + 43.39e^{-(x-1)/23.59}$	$y = 2.20 + 24.32e^{-(x-1)/11.46}$
Relaycropping	0	$y = 2.56 + 5.94e^{-(x-1)/14.13}$	$y = 0.52 + 2.57e^{-(x-1)/14.75}$
Monocropping-(R)	0	$y = 3.42 + 15.81e^{-(x-1)/19.59}$	$y = 1.05 + 8.10e^{-(x-1)/11.73}$
Intercropping	150	$y = 7.83 + 20.31e^{-(x-1)/24.33}$	$y = 2.12 + 10.14e^{-(x-1)/18.60}$

Monocropping-(I)	150	$y = 13.57 + 59.01e^{-(x-1)/18.17}$	$y = 5.24 + 21.04e^{-(x-1)/18.56}$
Relaycropping	150	$y = 3.13 + 10.94e^{-(x-1)/21.07}$	$y = 0.78 + 4.33e^{-(x-1)/17.57}$
Monocropping-(R)	150	$y = 4.83 + 31.94e^{-(x-1)/15.46}$	$y = 1.18 + 14.91e^{-(x-1)/13.21}$
		Cycle 3	
Intercropping	0	$y = 6.44 + 11.08e^{-(x-1)/12.53}$	$y = 1.59 + 4.88e^{-(x-1)/15.39}$
Monocropping-(I)	0	$y = 8.67 + 42.17e^{-(x-1)/11.50}$	$y = 2.59 + 23.08e^{-(x-1)/7.83}$
Relaycropping	0	$y = 4.36 + 13.15e^{-(x-1)/12.77}$	$y = 1.43 + 6.69e^{-(x-1)/15.82}$
Monocropping-(R)	0	$y = 5.63 + 35.78e^{-(x-1)/7.52}$	$y = 2.22 + 15.80e^{-(x-1)/7.51}$
Intercropping	150	$y = 8.15 + 17.55e^{-(x-1)/9.39}$	$y = 2.15 + 7.25e^{-(x-1)/10.81}$
Monocropping-(I)	150	$y = 11.52 + 48.67e^{-(x-1)/14.37}$	$y = 3.06 + 18.02e^{-(x-1)/14.65}$
Relaycropping	150	$y = 3.79 + 14.62e^{-(x-1)/14.55}$	$y = 1.06 + 4.79e^{-(x-1)/22.62}$
Monocropping-(R)	150	$y = 7.05 + 30.99e^{-(x-1)/8.24}$	$y = 1.85 + 11.67e^{-(x-1)/14.84}$

†: Equations are in the forms of $y = y_{ar} + (y_o - y_{ar})e^{-(x-1)/X_{cp}}$, where y_o and y_{ar} are peanut TDM or pod yield per plant at intraspecific competition free and its apparent residual, respectively; while X_{cp} is the peanut competitive density constant.

+: $PDMAX^{-2} = m^{-2}$.

°: In inter- and relaycropping, equations represent over three corn densities (2.7, 5.3, and 13.3 plants m^{-2}).

¶ and #: Monocroppings that correspond to inter- and relayplanting dates, respectively.

Table 6. Peanut competitive density constant (X_{cp}), potential total dry matter (TDM) or pod yield per plant at intraspecific competition free (y_o), and apparent residual of TDM or pod yield per plant (y_{ar}) under nitrogen x cropping system environments in three cycles of experimentation on a Malaysian histosol.

Cropping system	Nitrogen (kg ha^{-1})	TDM plant^{-1}			Pod yield plant^{-1}		
		X_{pc} (no. PDMAX^{-2})	y_o (g plant^{-1})	y_{ar} (g plant^{-1})	X_{pc} (no. PDMAX^{-2})	y_o (g plant^{-1})	y_{ar} (g plant^{-1})
				Cycle 1			
Intercropping†	0	16.6	21.2	5.5	13.6	10.1	2.0
Monocropping-(I)+	0	27.7	34.2	3.7	17.9	19.3	1.8
Relaycropping†	0	20.4	10.8	3.3	20.1	4.8	0.8
Monocropping-(R)°	0	19.4	22.3	4.6	22.4	9.6	1.0
Intercropping	150	25.7	34.1	9.2	27.1	11.5	2.1
Monocropping-(I)	150	13.6	80.6	13.5	9.9	45.4	5.6
Relaycropping	150	17.3	22.5	4.1	13.9	11.1	1.9
Monocropping-(R)	150	11.5	40.9	6.2	8.9	23.4	1.7
				Cycle 2			
Intercropping	0	24.9	20.7	4.3	13.9	10.0	1.8
Monocropping-(I)	0	23.6	47.8	4.4	11.5	26.5	2.2
Relaycropping	0	14.1	8.5	2.6	14.7	3.1	0.5
Monocropping-(R)	0	19.6	19.2	3.4	11.7	9.1	1.1
Intercropping	150	24.3	28.1	7.8	18.6	12.3	2.1

Monocropping-(I)	150	18.2	72.6	13.6	18.6	26.3	5.2
Relaycropping	150	21.1	14.1	3.1	17.6	5.1	0.8
Monocropping-(R)	150	15.5	36.8	4.8	13.2	16.1	1.2
				Cycle 3			
Intercropping	0	12.5	17.5	6.4	15.4	6.5	1.6
Monocropping-(I)	0	11.6	50.8	8.7	7.8	25.7	2.6
Relaycropping	0	12.8	17.5	4.4	15.8	8.1	1.4
Monocropping-(R)	0	7.5	41.4	5.6	7.5	18.0	2.2
Intercropping	150	9.4	25.7	8.2	10.8	9.4	2.1
Monocropping-(I)	150	14.4	60.2	11.5	14.6	21.1	3.1
Relaycropping	150	14.6	18.4	3.8	22.6	5.8	1.1
Monocropping-(R)	150	8.2	38.0	7.1	14.8	13.5	1.9

†: In inter- and relaycropping, the values represent over three corn densities (2.7, 5.3, and 13.3 plants m^{-2}).

+ and °: Monocroppings that correspond to inter- and relayplanting dates, respectively.

[Chew et al., 1979 (research on peat soil at 333,333 plants ha^{-2})], 24.3 g pod $plant^{-1}$ [Ishag, 1970 (research on Barberton variety on heavy Gezira clay at 166,667 plant ha^{-2})] and 7.3 g pod $plant^{-1}$ [Hauser and Buchanan, 1981 (research on Greenville sandy clay loam at about 665,025 plants ha^{-2} without weed-free maintenance)]. The above examples indicate that apparently some amounts (residuals) of peanut seed or pod yields per plant were present at the respective highest densities used, i.e., it did not reach the zero level despite the high densities. Working with wide density range (1.8 to 77.3 plant m^{-2}), Titeo-Kagho (1987) indicated that soybean (for Cobb and Davis cultivars) TDM and seed yields per plant tended to level off from 40 and 55 plants m^{-2}, respectively. The above examples strengthen the concept of apparent residual (undifferentiable amount) (y_{ar}) in peanut at high density (surviving plants per unit area) in considering response per plant vs. density relationships, i.e., as shown in Figures 2 to 7.

Table 6 shows that the y_{ar} values of TDM and pod yields per plant of N-fertilized monocropping-(I) in cycle 1 were 13.5 and 5.6 g $plant^{-1}$, respectively, which were higher than those in other environments. The y_{ar} values for the N-fertilized intercropping plots (9.2 and 2.1 g $plant^{-1}$ for TDM and pod yields, respectively) were apparently higher than those in the respective counterpart non-N-fertilized plots (5.5 and 2.0 g $plant^{-1}$). The lowest values were found from the non-N-fertilized relaycropping plots (3.3 and 0.8 g $plant^{-1}$ for TDM and pod yields per plant, respectively) (Table 6).

Similar trends were also observed in cycles 2 and 3. The above results suggest that higher y_{ar} values were obtained from better environments for a given genotype.

In all cycles, the y_o values of TDM and pod yields per plant of monocropping plots were higher than those in the counterpart inter- or relaycropping plots (Table 6). This suggests that the peanut potential total and reproductive yields per plant were greatly reduced by corn in the inter- and relaycropping systems. Table 6 also shows that the y_o values (with respect to TDM and pod yields) of N-treated plots were generally higher than those of their counterparts in non-N-fertilized plots. This indicates that the peanut individual potential growth and yield were also partly affected by environments that related to the fertility status of the soil.

Peanut competitive density constant (X_{cp}) is the required number of competitive plants per $PDMAX^2$ that will reduce the differentiable portion of per plant response to its e^{-1} = 37%. Based on the literature available, this density constant concept has probably not been used previously in plant density studies. Table 6 shows the X_{cp} values with respect to TDM for cycles 1, 2, and 3 were ranging from 11.5 to 25.7, 14.1 to 24.9, and 7.5 to 14.6 competitive plants $PDMAX^{-2}$, respectively, whereas the respective values that related to pod yield were 8.9 to 27.1, 11.5 to 18.6, and 7.5 to 22.6 plants $PDMAX^{-2}$. More importantly, X_{pc} could serve as an intrinsic index showing competitive peanut density dynamics in a given nitrogen x cropping system environment of a given locality.

In summary, the presented equations (Table 5) and response trends (Figures 2 to 7) show applicable equations (based on the proposed response per plant vs. density model) in either mono-, inter- or relaycropping environments in all three cycles.

Sweetcorn Total Dry Matter Yield Per Plant

Table 7 shows strong main effects of nitrogen (N), cropping system (CS) and corn density (C) in affecting sweetcorn total dry matter (TDM) per plant in all three cycles. Peanut density (P) main effect was significant, but with small F values, in all cycles. Some indicated significant interactions among treatments had relatively low F values (Table 7), and thus they were not as strong as the main effects of N, corn density and cropping system.

The above analyses indicate the importance of N-fertilization in individual sweetcorn growth on the Malaysian peat due to the high C:N ratios in these experimental plots (Table 1). The significant cropping system effects in the three cycles were mainly due to differences in TDM yield per plant of mono- and relaycropping vs. intercropping systems (Table 7). Figures 8, 9, and 10, and Appendix Table B-2 show that the relative differences were greater in the non-N-fertilized plots, especially at low corn density (2.7 plants m^{-2}). In N-fertilized intercroppings, the TDM per plant reduction due to increased peanut densities (5 to 80 plants m^{-2}) were only obvious in plots that had the highest C:N (24.8) (cycle 1), especially at 2.7 and 5.3 corn plants m^{-2} (Figure 8; Appendix Table B-2). In the non-N-fertilized intercropping, corn TDM yields per plant at lowest peanut

Table 7. Sweetcorn total dry matter (TDM) and ear yield per plant as affected by nitrogen rate, cropping system, sweetcorn density, and peanut density in three cycles of experimentation on a Malaysian histosol.

Treatment	Total dry matter			Ear yield		
	Cycle			Cycle		
	1	2	3	1	2	3
	g plant^{-1}					
Nitrogen (N)†						
0 kg ha^{-1}	38.0	67.9	55.5	26.9	55.6	44.7
150 kg ha^{-1}	107.1	108.3	95.3	123.4	110.6	98.4
LSD (0.05)	8.8	13.4	10.7	30.3	32.7	15.1
Cropping system (CS)†						
Intercropping (I)	57.2	78.1	61.3	56.4	69.0	47.7
Relaycropping (R)	84.3	96.0	86.3	92.5	94.0	91.4
Monocropping (M)	90.1	99.2	91.4	91.1	98.9	91.5
LSD (0.05)‡--I vs. R	7.8	6.6	5.3	8.1	7.6	7.4
LSD (0.05)‡--M vs. (I or R)	13.4	11.4	9.2	13.9	13.1	12.9
Corn density (C)†						
2.7 plants m^{-2}	111.4	126.6	111.3	128.4	132.7	128.8
5.3 plants m^{-2}	69.8	87.3	74.8	73.8	82.7	65.3
13.3 plants m^{-2}	36.3	50.5	40.0	23.3	33.9	20.5
LSD (0.05)	9.1	7.7	6.2	9.4	8.9	8.7
Peanut density (P)°						
5 plants m^{-2}	80.4	95.4	77.8	77.5	88.5	73.2
10 plants m^{-2}	77.7	88.8	78.7	77.0	80.6	77.4

20 plants m^{-2}	73.8	80.7	67.9	79.8	74.0	64.9
40 plants m^{-2}	60.1	89.4	72.6	62.7	86.8	67.9
80 plants m^{-2}	61.9	80.9	72.0	70.6	77.8	64.3
LSD (0.05)	9.3	8.5	7.8	11.4	9.9	11.2
			F statistic (F value)			
N†	399.59**	46.62**	74.91**	60.29**	13.08*	71.04**
CS	24.58**	16.94**	48.87**	33.03**	23.93**	68.69**
C	86.83**	123.66**	171.18**	166.68**	148.73**	198.76**
N x CS	0.67^{ns}	5.24**	7.30**	0.93^{ns}	5.24**	2.42^{+}
N x C	10.37**	5.85**	3.75*	41.29**	4.09*	12.33**
CS x C	4.17**	5.35**	9.23**	8.93**	6.53**	18.45**
N x CS x C	0.56^{ns}	0.69^{ns}	2.22^{+}	0.64^{ns}	1.26^{ns}	1.49^{ns}
P°	6.47**	4.24**	2.34^{+}	1.80^{ns}	2.88*	1.65^{ns}
P x N	1.22^{ns}	3.41*	0.79^{ns}	1.24^{ns}	2.37^{+}	0.29^{ns}
P x CS	3.62**	0.34^{ns}	1.44^{ns}	1.35^{ns}	0.33^{ns}	1.08^{ns}
P x C	3.62**	1.67^{ns}	0.96^{ns}	1.28^{ns}	0.98^{ns}	1.01^{ns}
P x N x CS	2.65*	1.35^{ns}	1.85^{ns}	1.56^{ns}	0.84^{ns}	0.28^{ns}
P x N x C	1.52^{ns}	1.17^{ns}	0.66^{ns}	2.42*	1.11^{ns}	0.39^{ns}
P x CS x C	2.41*	1.34^{ns}	0.60^{ns}	0.79^{ns}	1.31^{ns}	0.37^{ns}
P x CS x C x N	2.11*	1.21^{ns}	0.32^{ns}	0.91^{ns}	0.59^{ns}	0.10^{ns}

†: Due to the design employed, the ANOVA was done according to the split-plot design; main plots: N, sub-plots: CS and C.

‡: Due to the design employed, inter- and relaycropping had 120 observations each, while monocropping had only 24. Thus, two respective LSD values were used.

°: Due to the design employed (excluding corn monocropping which had no peanut density effect, and that additionally to avoid missing cell in the analysis), the ANOVA was done according to the split-split-plot design, i.e., main plots: N; sub-plots: CS and C; sub-sub-plots: P. Only F statistics of P and its related interaction effects are shown.

+, *, **, and ns: Significant at $\alpha = 0.10$, $\alpha = 0.05$, and $\alpha = 0.01$ levels, and not significant, respectively.

Figure 8. Relationships between sweetcorn total dry matter or ear yield per plant in mono-, inter-, and relaycropping environments of Cycle 1 experimentation on a Malaysian histosol. Response trends in inter- and relaycropping represent over five peanut densities. $CDMAX^2 = 3.24$ m^2. The LSD bars shown are used for comparison in (a) †: between monocropping yield and mean yield (over five peanut densities) of inter- or relaycropping at same nitrogen x corn density combination, (b) ‡: between means of inter- and relaycropping at same nitrogen x corn density combination, and (c) °: between two peanut density yields at same nitrogen x cropping system x corn density combination (only for inter- and relaycropping). The respective values of effects and LSD bars shown are indicated in Appendix Table B-2.

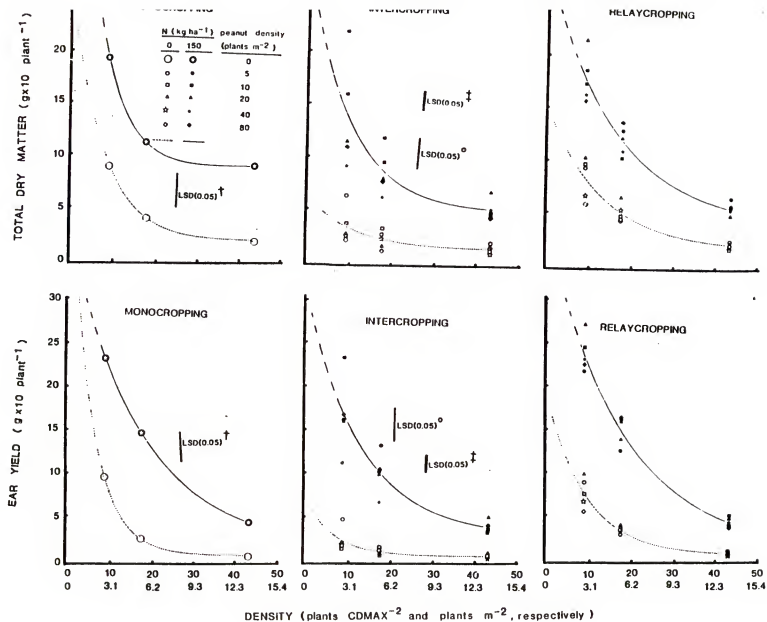

TOTAL DRY MATTER (g x10 plant⁻¹)
EAR YIELD (g x10 plant⁻¹)
N (kg ha⁻¹)
0
150
peanut density (plants m⁻²)
0
5
10
20
40
80
LSD(0.05)†
LSD(0.05)‡
LSD(0.05)°
MONOCROPPING
INTERCROPPING
RELAYCROPPING
0 10 20 30 40 50
0 3.1 6.2 9.3 12.3 15.4
DENSITY (plants CDMAX⁻² and plants m⁻², respectively)

Figure 9. Relationships between sweetcorn total dry matter or ear yield per plant in mono-, inter-, and relaycropping environments of Cycle 2 experimentation on a Malaysian histosol. Response trends in inter- and relaycropping represent over five peanut densities. $CDMAX^2 = 3.24$ m^2. The LSD bars shown are used for comparison in (a) †: between monocropping yield and mean yield (over five peanut densities) of inter- or relaycropping at same nitrogen x corn density combination, (b) ‡: between means of inter- and relaycropping at same nitrogen x corn density combination, and (c) °: between two peanut density yields at same nitrogen x cropping system x corn density combination (only for inter- and relaycropping). The respective values of effects and LSD bars shown are indicated in Appendix Table B-2.

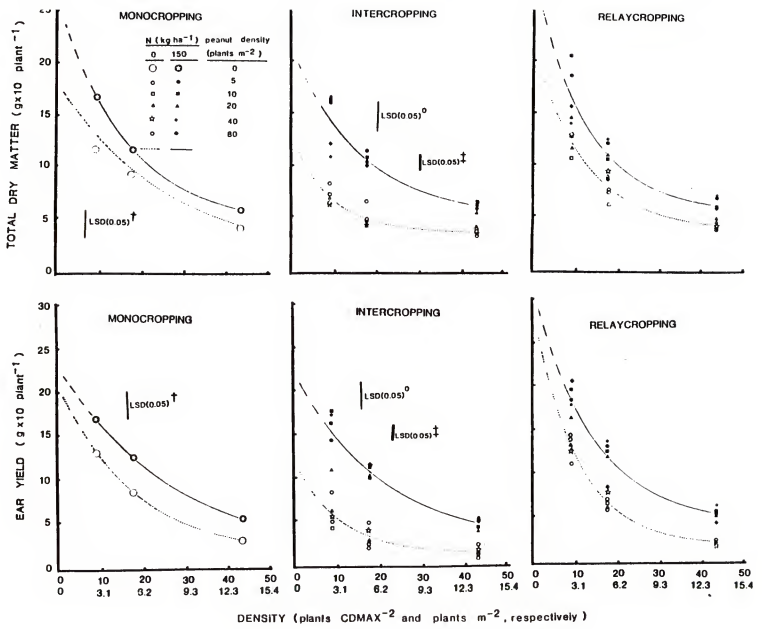
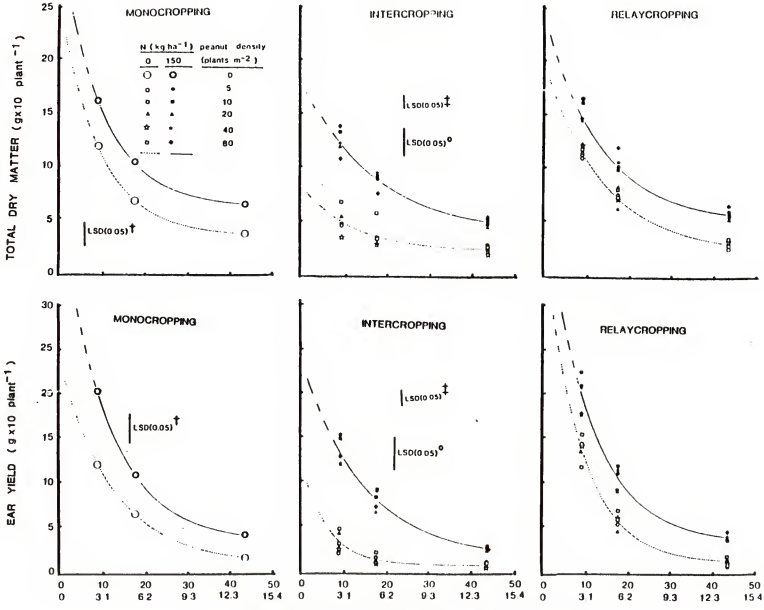

MONOCROPPING
INTERCROPPING
RELAYCROPPING
N (kg ha⁻¹) peanut density
0 150 (plants m⁻²)
0 0
5
10
20
40
80
LSD(0.05)†
LSD(0.05)°
LSD(0.05)‡
TOTAL DRY MATTER (g×10 plant⁻¹)
EAR YIELD (g×10 plant⁻¹)
0 10 20 30 40 50
0 3.1 6.2 9.3 12.3 15.4
DENSITY (plants CDMAX⁻² and plants m⁻², respectively)

Figure 10. Relationships between sweetcorn total dry matter or ear yield per plant in mono-, inter-, and relaycropping environments of Cycle 3 experimentation on a Malaysian histosol. Response trends in inter- and relaycropping represent over five peanut densities. $CDMAX^2$ = 3.24 m^2. The LSD bars shown are used for comparison in (a) †: between monocropping yield and mean yield (over five peanut densities) of inter- or relaycropping at same nitrogen x corn density combination, (b) ‡: between means of inter- and relaycropping at same nitrogen x corn density combination, and (c) °: between two peanut density yields at same nitrogen x cropping system x corn density combination (only for inter- and relaycropping). The respective values of effects and LSD bars shown are indicated in Appendix Table B-2.


MONOCROPPING
INTERCROPPING
RELAYCROPPING
N (kg ha⁻¹)
0
150
peanut density (plants m⁻²)
0
5
10
20
40
80
LSD(0.05)†
LSD(0.05)‡
LSD(0.05)°
TOTAL DRY MATTER (g x10 plant⁻¹)
EAR YIELD (g x10 plant⁻¹)
0 10 20 30 40 50
0 3.1 6.2 9.3 12.3 15.4
DENSITY (plants CDMAX⁻² and plants m⁻², respectively)

density (5 or sometimes 10 plants m^{-2}) were generally consistently higher than those at higher peanut densities (10 to 80 plants m^{-2}), especially at lower corn densities in all cycles (Figures 8, 9, and 10; Appendix Table B-2). These findings suggest that the introduction of intercrop peanut was important in reducing individual corn plant growth, especially without N fertilization. Furthermore, corn growth reductions in intercropping plots by increased peanut densities were observed in N-fertilized high C:N plot (cycle 1) and non-N-fertilized plots regardless of C:N values.

Relayplanted peanut (one day after 50% corn tasseling) provided about 27 days of immature peanut-maturing corn overlap, thus resulting in very low peanut competition for nutrients and other growth limiting factors to the base-crop corn. This led to general insignificant differences in sweetcorn TDM yield per plant between mono- and relaycropping treatments in all cycles (Figures 8, 9, and 10; Appendix Table B-2). The corn TDM yields per plant decreased with increasing density in all N x cropping system x peanut density environments of all three cycles (Figures 8, 9, and 10; Appendix Table B-2).

Sweetcorn Ear Yield Per Plant

Response trends in ear yield per plant and statistical significance due to the effects of N, cropping system, corn density and their interactions were similar to those for TDM yields per plant in all three cycles (Table 7; Figures 8, 9, and 10; Appendix Table B-2). It should be further emphasized that the corn density main effects in all three cycles on ear yield per plant were much larger than those on TDM yield per plant, indicating that individual plant

reproductive growth was more affected by corn density than individual plant total growth. Latta (1889) as cited by Kohnke and Miles (1951) reported that denser planting gave higher ear yields, but with smaller ears. Table 7 shows that the average ear yields per plant were reduced sharply by increasing corn plant density in all three cycles.

Ear yield per plant was generally reduced by the presence of peanut (intercropping), especially with a greater relative effect in the non-N-fertilized plots and at the higher C:N ratio (cycle 1) regardless of N treatment (Figures 8, 9, and 10; Appendix Table B-2). As with TDM per plant, relayplanted peanut did not generally reduce corn ear yield per plant in any cycle.

Sweetcorn Total Dry Matter and Ear Yield Per Plant Models

In investigating the mathematical model in relating TDM or ear yield per plant with corn density, the relationships by N x cropping system environments are presented. The relationship curves under the above environments are shown in Figures 8, 9, and 10.

Table 8 shows equations relating sweetcorn TDM or ear yields per plant with corn densities [plants $CDMAX^{-2}$ = plants $(1.8\ m)^{-2}$ = plants $3.24^{-1}\ m^{-2}$]. In all environments of all cycles, TDM or ear yields per plant decreased exponentially with increasing corn densities to the respective residual levels (y_{ar}). Working with wide density range (0.8 to 15.4 plants m^{-2}), Tetio-Kagho (1987) indicated that TDM and kernal yields per plant of corn in monocropping and in associations with soybean of 3.0, 8.5 and 24.0 soybean plants m^{-2} tended to level off at higher corn densities.

Table 8. Equations† of sweetcorn total dry matter (TDM) and ear yield per plant (y) against corn density (x) for $1 \leq x \leq 43.1$ plants $CDMAX^{-2++}$ under nitrogen x cropping system environments in three cycles of experimentation on a Malaysian histosol.

Cropping system	Nitrogen (kg ha^{-1})	TDM $plant^{-1}$	Ear yield $plant^{-1}$
		Cycle 1	
Intercropping°	0	$y = 11.90 + 44.65e^{-(x-1)/10.64}$	$y = 4.58 + 55.86e^{-(x-1)/6.57}$
Relaycropping°	0	$y = 15.67 + 120.75e^{-(x-1)/12.95}$	$y = 4.99 + 159.55e^{-(x-1)/9.44}$
Monocropping	0	$y = 17.42 + 203.53e^{-(x-1)/7.39}$	$y = 6.36 + 355.24e^{-(x-1)/5.50}$
Intercropping	150	$y = 47.65 + 205.83e^{-(x-1)/9.83}$	$y = 28.43 + 253.63e^{-(x-1)/12.80}$
Relaycropping	150	$y = 38.18 + 222.57e^{-(x-1)/16.18}$	$y = 10.56 + 343.80e^{-(x-1)/17.82}$
Monocropping	150	$y = 88.30 + 389.20e^{-(x-1)/5.78}$	$y = 14.34 + 332.83e^{-(x-1)/17.54}$
		Cycle 2	
Intercropping	0	$y = 36.57 + 77.63e^{-(x-1)/9.06}$	$y = 12.92 + 94.22e^{-(x-1)/10.58}$
Relaycropping	0	$y = 36.30 + 159.01e^{-(x-1)/12.27}$	$y = 15.20 + 239.28e^{-(x-1)/10.33}$
Monocropping	0	$y = 10.40 + 163.34e^{-(x-1)/26.69}$	$y = 11.98 + 182.83e^{-(x-1)/17.94}$
Intercropping	150	$y = 51.07 + 145.62e^{-(x-1)/16.54}$	$y = 23.18 + 186.06e^{-(x-1)/20.77}$
Relaycropping	150	$y = 53.80 + 206.83e^{-(x-1)/12.31}$	$y = 39.22 + 248.72e^{-(x-1)/13.95}$
Monocropping	150	$y = 44.49 + 190.76e^{-(x-1)/16.79}$	$y = 8.24 + 210.06e^{-(x-1)/27.52}$

		Cycle 3	
Intercropping	0	$y = 21.10 + 55.29e^{-(x-1)/11.77}$	$y = 5.48 + 92.32e^{-(x-1)/6.16}$
Relaycropping	0	$y = 20.98 + 160.94e^{-(x-1)/13.90}$	$y = 8.89 + 313.93e^{-(x-1)/8.62}$
Monocropping	0	$y = 33.90 + 185.74e^{-(x-1)/9.57}$	$y = 6.92 + 206.04e^{-(x-1)/12.72}$
Intercropping	150	$y = 37.38 + 132.92e^{-(x-1)/16.99}$	$y = 14.38 + 200.44e^{-(x-1)/14.39}$
Relaycropping	150	$y = 49.08 + 175.44e^{-(x-1)/13.14}$	$y = 31.52 + 348.50e^{-(x-1)/10.46}$
Monocropping	150	$y = 60.93 + 213.28e^{-(x-1)/9.92}$	$y = 32.20 + 340.22e^{-(x-1)/10.94}$

†: Equations are in the forms of $y = y_{ar} + (y_o - y_{ar})e^{-(x-1)/X_{cc}}$, where y_o and y_{ar} are corn TDM or ear yield per plant at intraspecific competition free and its apparent residual, respectively; while X_{cc} is the corn competitive density constants.

++: $CDMAX^{-2} = (1.8\ m)^{-2} = 3.24^{-1}\ m^{-2}$.

°: In inter- and relaycropping, equations represent over five peanut densities (5, 10, 20, 40, and 80 plants m^{-2}).

Table 9 gives the estimates of apparent residuals (y_{ar}), yields at intraspecific competition free (y_o), and corn competitive density constants (X_{cc}) for TDM and ear yields per plant of all cycles. In all cycles, y_{ar} values for ear yield per plant from N-fertilized plots were generally higher than those respective values from non-N-fertilized plots (Table 8). Similar trends were also found for TDM per plant. These results suggest that apparent residuals of TDM and ear yields per plant were greatly affected by N status of the soil. It logically follows that y_{ar} would also be affected by cultivar and planting pattern, or other management strategies.

In all three cycles, y_o values for TDM or ear yields per plant of mono- and relaycropping were higher than those of intercropping in both N-fertilized and non-N-fertilized plots (Table 9). This indicates that potentials in corn growth and reproductive yield were affected by the presence of the intercrop peanut. Table 9 also generally shows that y_o values for both TDM and ear yields per plant in N-fertilized mono- and relaycropping plots were higher than those in the counterpart non-N-fertilized treatments. In all three cycles, the y_o values of N-fertilized intercropping plots were much higher than those of the counterpart non-N-fertilized intercropping plots. The above two situations suggest that, in the absence of or with relatively short overlapping period with peanut, the corn total and reproductive yield potentials were reduced by low N fertilization. Furthermore, the relative reduction was greater with the presence of peanut during the whole corn cropping period.

Table 9. Corn competitive density constants (X_{cc}), potential total dry matter (TDM) or ear yield per plant at intraspecific competition free (y_o), and apparent residual of TDM or ear yield per plant (y_{ar}) under nitrogen x cropping system environments in three cycles of experimentation on a Malaysian histosol.

Cropping system	Nitrogen (kg ha^{-1})	TDM $plant^{-1}$ X_{cc} (no. $CDMAX^{-2}$)	TDM $plant^{-1}$ y_o (g $plant^{-1}$)	TDM $plant^{-1}$ y_{ar} (g $plant^{-1}$)	Ear yield $plant^{-1}$ X_{cc} (no. $CDMAX^{-2}$)	Ear yield $plant^{-1}$ y_o (g $plant^{-1}$)	Ear yield $plant^{-1}$ y_{ar} (g $plant^{-1}$)
				Cycle 1			
Intercropping†	0	10.6	56.5	11.9	6.6	60.4	4.6
Relaycropping†	0	12.9	136.4	15.7	9.4	164.5	5.0
Monocropping	0	7.4	220.5	17.4	5.5	361.6	6.4
Intercropping	150	9.8	253.8	47.6	12.8	282.1	28.4
Relaycropping	150	16.2	260.7	38.2	17.8	354.4	10.6
Monocropping	150	5.8	477.5	88.3	17.5	347.2	14.3
				Cycle 2			
Intercropping	0	9.1	114.2	36.6	10.6	107.1	12.9
Relaycropping	0	12.3	195.3	36.3	10.3	254.5	15.2
Monocropping	0	26.7	173.7	10.4	17.9	194.8	12.0
Intercropping	150	16.5	196.7	51.1	20.8	209.3	23.2
Relaycropping	150	12.3	260.6	53.8	13.9	287.9	39.2
Monocropping	150	16.8	235.3	44.5	27.5	218.3	8.2

		Cycle 3					
Intercropping	0	11.8	76.4	21.1	6.2	97.8	5.5
Relaycropping	0	13.9	181.9	20.9	8.6	322.8	8.9
Monocropping	0	9.6	219.6	33.9	12.7	212.9	6.9
Intercropping	150	17.0	170.3	37.4	14.4	214.8	14.4
Relaycropping	150	13.1	224.5	49.1	10.5	380.0	31.5
Monocropping	150	9.9	274.2	60.9	10.9	372.4	32.2

†: In inter- and relaycropping, the values represent over five peanut densities (5, 10, 20, 40, and 80 plants m^{-2}).

Table 9 shows that the corn competitive density constants (X_{cc}) relative to TDM yield per plant in cycles 1, 2, and 3 were in the ranges of 5.8 to 16.2, 9.1 to 26.7, and 9.6 to 17.0 competitive plants $CDMAX^{-2}$, respectively, whereas the respective ranges relative to ear yield per plant were 5.5 to 17.8, 10.3 to 27.5, and 6.2 to 14.4 plants $CDMAX^{-2}$. In general, the reduction of ear yield per plant needed fewer competitive plants in non-N-fertilized plots than in N-fertilized plots (Table 9) which might suggest that the readily available resources for ear development were exhausted earlier in the non-N- than in the N-fertilized plots.

Peanut Total Dry Matter Yield Per Hectare Response and Model

Table 10 shows that peanut density (P) had the greatest effect among other treatments and their interaction terms in affecting TDM per hectare (ha) in all three cycles. Furthermore, the N main effect was highly significant in cycle 2 (previously grown to corn), while system-corn density (S-C) main effect was highly significant in all cycles. With relatively low F values as compared to the F values related to the above, significant N x S and S-C x P and N x P interactions in affecting TDM per ha were detected in all cycles (significant N x P in cycles 1 and 2 only) (Table 10).

Figures 11, 12, and 13, and Appendix Table B-3 show that peanut TDM yields per ha were much higher in N-fertilized plots than those in non-N-fertilized under both intercropping and monocropping-(I) environments, especially at higher peanut densities (generally > 10 plants m^{-2}) in all cycles. The above differences were much larger in cycles 1 and 2 than in cycle 3. The differences were small in relaycropping and monocropping-(R) environments, especially near zero

Table 10. Peanut total dry matter (TDM) and pod yield per hectare as affected by nitrogen rate, system-corn density, and peanut density in three cycles of experimentation on a Malaysian histosol.

Treatment	Total dry matter			Pod yield		
	Cycle			Cycle		
	1	2	3	1	2	3
	kg ha^{-1}					
Nitrogen (N)						
0 kg ha^{-1}	2127	2014	2286	776	648	789
150 kg ha^{-1}	3649	3205	2728	1305	1028	875
LSD (0.05)	1620	445	426	399	307	103
System-corn density (S-C)						
Intercropping at 2.7 plants m^{-2}	4100	3546	3163	1312	1243	989
Intercropping at 5.3 plants m^{-2}	3209	3083	2380	1099	935	698
Intercropping at 13.3 plants m^{-2}	3067	2578	2226	953	794	590
Relaycropping at 2.7 plants m^{-2}	1511	1328	1703	507	376	713
Relaycropping at 5.3 plants m^{-2}	2018	1279	1559	831	374	660
Relaycropping at 13.3 plants m^{-2}	1695	1252	1950	728	292	633
Monocropping-(I)	4947	5500	4559	1998	1991	1395
Monocropping-(R)	2556	2310	2515	899	701	977
LSD (0.05)	902	585	570	331	286	202
Peanut density (P)						
5 plants m^{-2}	1360	1183	1053	580	485	444

10 plants m^{-2}	1854	1755	1545	779	635	587
20 plants m^{-2}	2617	2401	1998	961	775	706
40 plants m^{-2}	3532	3343	2874	1231	989	978
80 plants m^{-2}	5078	4365	5063	1653	1307	1446
LSD (0.05)	369	324	293	154	123	95
			F Statistics (F value)			
N	7.95^{+}	66.82**	9.43^{+}	14.96*	12.55*	6.55^{+}
S-C	14.12**	48.59**	21.10**	14.25**	31.35**	13.75**
P	111.53**	111.25**	211.81**	53.49**	49.29**	131.96**
N x S-C	3.53**	4.18**	1.91^{a}	2.44*	4.41**	1.62^{ns}
N x P	7.43**	9.31**	1.35^{ns}	5.73**	4.72**	0.43^{ns}
S-C x P	2.05**	3.56**	4.25**	1.34^{ns}	3.57**	1.92**
N x S-C x P	1.37^{ns}	1.85**	0.82^{ns}	1.42^{ns}	2.34**	1.27^{ns}

†: N, S-C, and P were as main-, sub-, and sub-sub-plots, respectively.

+, *, **, and ns: Significant at $\alpha = 0.10$, $\alpha = 0.05$, and $\alpha = 0.01$ levels, and not significant, respectively.

Figure 11. Relationships between peanut total dry matter per ha and plant density in mono-, inter-, and relaycropping environments of Cycle 1 experimentation on a Malaysian histosol. Monocropping-(I) and monocropping-(R) indicate monocroppings that correspond to inter- and relayplanting dates, respectively. Response trends in inter- and relaycropping represent over three sweetcorn densities. $PDMAX^2 = 1.0\ m^2$. The LSD bar shown is for comparison between two system-corn density (cropping system at each corn density) yields at same nitrogen x peanut density combination. The respective values of effects and LSD bar shown are indicated in Appendix Table B-3.

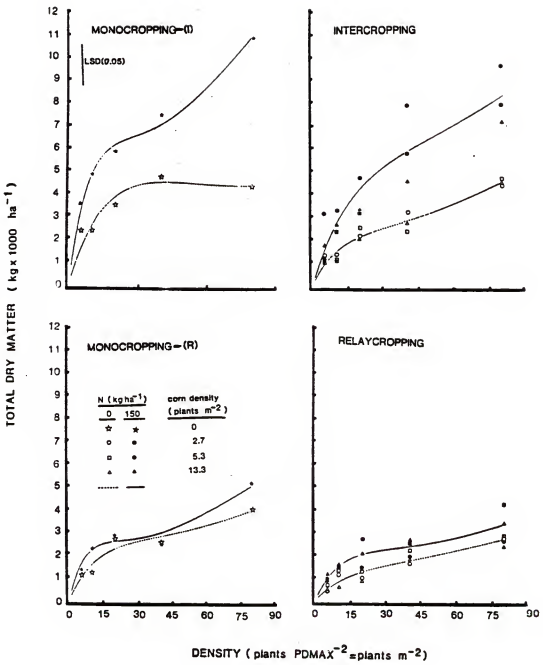

MONOCROPPING-(I)
LSD(0.05)
INTERCROPPING
MONOCROPPING-(R)
RELAYCROPPING
N (kg ha⁻¹)
0
150
corn density
(plants m⁻²)
0
2.7
5.3
13.3
TOTAL DRY MATTER (kg x 1000 ha⁻¹)
DENSITY (plants PDMAX⁻² = plants m⁻²)

Figure 12. Relationships between peanut total dry matter and plant density in mono-, inter-, and relaycropping environments of Cycle 2 experimentation on a Malaysian histosol. Monocropping-(I) and monocropping-(R) indicate monocroppings that correspond to inter- and relayplanting dates, respectively. Response trends in inter- and relaycropping represent over three sweetcorn densities. $PDMAX^2$ = 1.0 m^2. The LSD bar shown is for comparison between two system-corn density (cropping system at each corn density) yields at same nitrogen x peanut density combination. The respective values of effects and LSD bar shown are indicated in Appendix Table B-3.

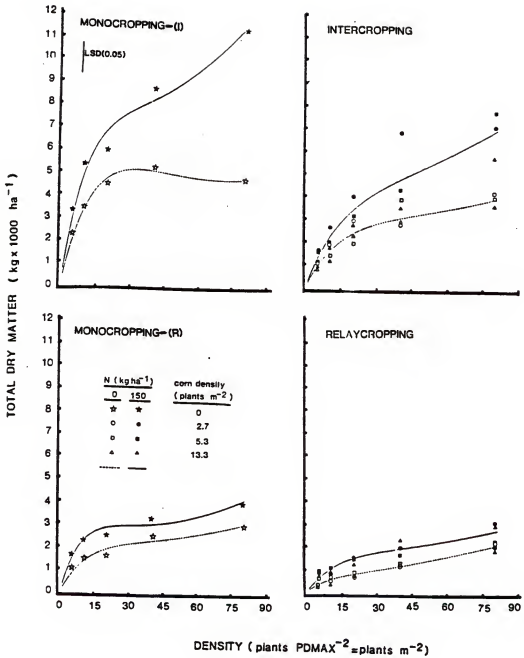
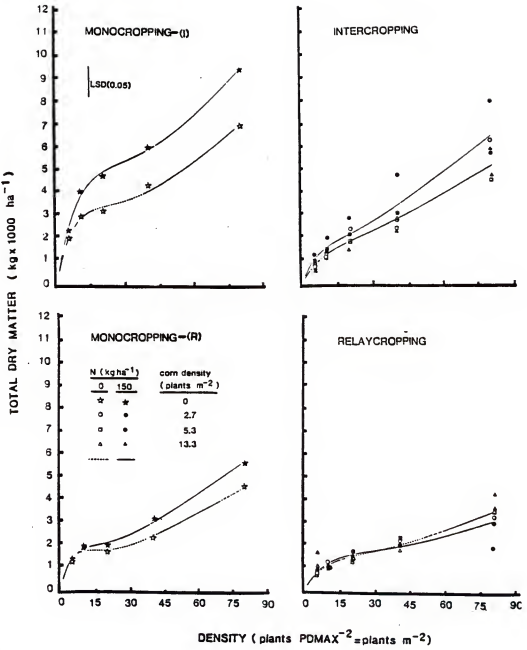

MONOCROPPING=(I)
LSD(0.05)
INTERCROPPING
MONOCROPPING=(R)
RELAYCROPPING
N (kg ha⁻¹)
0
150
corn density
(plants m⁻²)
0
2.7
5.3
13.3
TOTAL DRY MATTER (kg x 1000 ha⁻¹)
DENSITY (plants PDMAX⁻²=plants m⁻²)

Figure 13. Relationships between peanut total dry matter per ha and plant density in mono-, inter-, and relaycropping environments of Cycle 3 experimentation on a Malaysian histosol. Monocropping-(I) and monocropping-(R) indicate monocroppings that correspond to inter- and relayplanting dates, respectively. Response trends in inter- and relaycropping represent over three sweetcorn densities. $PDMAX^2 = 1.0\ m^2$. The LSD bar shown is for comparison between two system-corn density (cropping system at each corn density) yields at same nitrogen x peanut density combination. The respective values of effects and LSD bar shown are indicated in Appendix Table B-3.


MONOCROPPING-(I)
LSD(0.05)
INTERCROPPING
MONOCROPPING-(R)
N (kg ha⁻¹)
0
150
corn density
(plants m⁻²)
0
2.7
5.3
13.3
RELAYCROPPING
TOTAL DRY MATTER (kg x 1000 ha⁻¹)
DENSITY (plants PDMAX⁻²=plants m⁻²)

in monocropping-(R) in cycle 3 (Figure 11). The above results indicate the importance of N fertilization in peanut growth on peat soil.

Figures 11, 12, and 13, and Appendix Table B-3 indicate highest TDM per ha in monocropping-(I) compared to those in inter- and relaycropping (lowest) environments. The average TDM yields in cycle 1 of N-fertilized plots in the above environments were 6477, 4561, and 2071 kg ha^{-1}, respectively. This indicates that, on the average, 30 and 68% reductions in peanut total growth were due to corn in inter- and relaycropping, respectively. Higher reduction in relaycropping was probably mainly due to low available N and other nutrients (due to nutrient loss and/or uptake by earlier growth of base-corn crop). This is supported by trends shown in Figures 11, 12, and 13, and Appendix Table B-3. In all cycles, the figures show that with N fertilization, the TDM per ha in the monocropping-(R) plots (where N and other elements were applied at interplanting time) were much lower than those in the monocropping-(I), whereas monocropping-(R) TDM yields were only slightly higher than those in relaycroppings. Corn TDM yields per ha in the N-fertilized relaycropping plots were increased by corn density (Figures 17, 18, and 19; and Appendix Table B-4), whereas no consistent corn density effects on N-fertilized relayplanted peanut TDM yield were observed (Figures 11, 12, and 13; Appendix Table B-3). Since peanut growth was signficantly affected by N, and peanut being a C3 plant, i.e., where C3 is characterized by low light saturation (Ludlow, 1976; Gardner et al., 1985), the above situations suggest that relaycrop peanut growth (TDM per ha) was

reduced more by low nutrients (especially N) than by limiting light (short relaycrop peanut-corn overlapping duration). By considering time required for seedling emergence (7 to 14 days), the actual association between immature peanut and maturing sweetcorn was only about 12 to 19 days in relaycropping treatment. The average TDM yields per ha in the non-N-fertilized plots of mono-, inter-, and relaycropping in cycle 1 were 3417, 2356, and 1412 kg ha^{-1}, respectively (31 and 59% TDM reductions by corn in inter- and relaycropping, respectively). Generally corn growth without N on Malaysian peat was stunted, and thus probably providing more light to inter- or relayplanted peanut. It is therefore suggested that reduced inter- and relaycrop peanut TDM yields per ha without N fertilization were primarily due to competition for nutrients or other edaphic growth limiting factors than due to light limitation. The longer the corn was grown before relayplanting, the lower would be the residual nutrients available for relayplanted peanut. All the above trends were also observed in cycles 2 and 3. Generally, the peanut TDM yields per ha at 2.7 corn plants m^{-2} were consistently reduced by increasing corn density in the N and non-N (at lesser extent) intercropping plots among five peanut densities of all cycles (Figures 11, 12, and 13; Appendix Table B-3). The above findings indicate that, in addition to total peanut growth reduction due to the corn presence (in intercropping), further substantial reductions due to increased corn density were observed in N-fertilized intercropping plots of all cycles.

Figures 11, 12, and 13 indicate increases in peanut TDM yields per ha with peanut densities in all environments tested (nitrogen x cropping system). In each cycle, the highest TDM per ha was found at the highest density (80 plants m^{-2}) of N-fertilized monocropping-(I) plot. The above results suggest that planting density and peanut type were important factors in determining total peanut growth (TDM per ha) in the tropical oligotrophic peat environments.

Table 11 shows the SAS PROC NLIN solution for the values of y_o, y_{ar}, and X_o for TDM and pod yield per ha of peanut based on Eq. (33). The differentiable response ratio (DRR) $[(y_o - y_{ar}):y_{ar}]$ that couples with each competitive density constant (X_{cp}) can be used as a guide in describing the shape of TDM per ha vs. density relationship. The TDM per ha vs. density relationships in the non-N-fertilized monocropping-(I) plots of cycles 1 and 2 were asymptotic (Figures 11 and 12). This was due to high X_{cp} values (27.7 and 23.6 plants $PDMAX^{-2}$ for cycles 1 and 2, respectively) coupled with moderately high DRR values (8.4 and 9.8). This suggests that at higher density in the above environments, the density increments were compensated by reduced growth per plant and thus gave constant TDM yield per ha. However, with relatively low DRR values and with high X_{cp} constants, the TDM per ha vs. density relationships were the increasing trend in the N- and non-N-fertilized intercroppings, N- and non-N-fertilized relaycroppings, and non-N-fertilized monocropping-(R) of cycle 1 (Figure 11). The DRR values in the above environments were 2.7, 2.8, 4.5, 2.3, and 3.8, respectively, while the respective

Table 11. Equations† of peanut total dry matter (TDM) and pod yield per hectare (Y) against peanut density (x) for $1 < x < 80$ plant $PDMAX^{-2+}$ and differentiable response ratio (DRR) under nitrogen x cropping system environments in three cycles of experimentation on a Malaysian histosol.

Cropping system	Nitrogen (kg ha^{-1})	TDM ha^{-1} Equation	DRR°	Pod yield ha^{-1} Equation	DRR°
		Cycle 1			
Intercropping¶	0	$Y = (5.52x + 15.70xe^{-(x-1)/16.69})C$	2.8	$Y = (2.02x + 8.06xe^{-(x-1)/13.61})C$	4.0
Monocropping-(I)#	0	$Y = (3.65x + 30.59xe^{-(x-1)/27.72})C$	8.4	$Y = (1.85x + 17.44xe^{-(x-1)/17.88})C$	9.4
Relaycropping¶	0	$Y = (3.28x + 7.55xe^{-(x-1)/20.42})C$	2.3	$Y = (0.80x + 4.03xe^{-(x-1)/20.12})C$	5.0
Monocropping-(R)++	0	$Y = (4.63x + 17.64xe^{-(x-1)/19.39})C$	3.8	$Y = (1.03x + 8.56xe^{-(x-1)/22.37})C$	8.3
Intercropping	150	$Y = (9.21x + 24.85xe^{-(x-1)/25.73})C$	2.7	$Y = (2.14x + 9.37xe^{-(x-1)/27.13})C$	4.4
Monocropping-(I)	150	$Y = (13.48x + 67.15xe^{-(x-1)/13.85})C$	5.0	$Y = (5.55x + 39.82xe^{-(x-1)/9.87})C$	7.2
Relaycropping	150	$Y = (4.06x + 18.41xe^{-(x-1)/17.25})C$	4.5	$Y = (1.95x + 9.18xe^{-(x-1)/13.93})C$	5.0
Monocropping-(R)	150	$Y = (6.23x + 34.73xe^{-(x-1)/11.51})C$	5.6	$Y = (1.72x + 21.68xe^{-(x-1)/8.96})C$	12.6
		Cycle 2			
Intercropping	0	$Y = (4.25x + 16.43xe^{-(x-1)/24.93})C$	3.9	$Y = (1.78x + 8.19xe^{-(x-1)/13.90})C$	4.6
Monocropping-(I)	0	$Y = (4.42x + 43.39xe^{-(x-1)/23.59})C$	9.8	$Y = (2.20x + 24.32xe^{-(x-1)/11.46})C$	11.1
Relaycropping	0	$Y = (2.56x + 5.94xe^{-(x-1)/14.13})C$	2.3	$Y = (0.52x + 2.57xe^{-(x-1)/14.75})C$	4.9
Monocropping-(R)	0	$Y = (3.42x + 15.81xe^{-(x-1)/19.59})C$	4.6	$Y = (1.05x + 8.10xe^{-(x-1)/11.73})C$	7.7
Intercropping	150	$Y = (7.83x + 20.31xe^{-(x-1)/24.33})C$	2.6	$Y = (2.12x + 10.14xe^{-(x-1)/18.60})C$	4.8

Monocropping-(I)	150	$Y = (13.57x + 59.01xe^{-(x-1)/18.17})C$	4.3	$Y = (5.24x + 21.04xe^{-(x-1)/18.56})C$	4.0
Relaycropping	150	$Y = (3.13x + 10.94xe^{-(x-1)/21.07})C$	3.5	$Y = (0.78x + 4.33xe^{-(x-1)/17.57})C$	5.6
Monocropping-(R)	150	$Y = (4.83x + 31.94xe^{-(x-1)/15.46})C$	6.6	$Y = (1.18x + 14.91xe^{-(x-1)/13.21})C$	12.6
		- - - - - - - - - - - - - - - - - - Cycle 3 - - - - - - - - - - - - - - - - - -			
Intercropping	0	$Y = (6.44x + 11.08xe^{-(x-1)/12.53})C$	1.7	$Y = (1.59x + 4.88xe^{-(x-1)/15.39})C$	3.1
Monocropping-(I)	0	$Y = (8.67x + 42.17xe^{-(x-1)/11.50})C$	4.9	$Y = (2.59x + 23.08xe^{-(x-1)/7.83})C$	8.9
Relaycropping	0	$Y = (4.36x + 13.15xe^{-(x-1)/12.77})C$	3.0	$Y = (1.43x + 6.69xe^{-(x-1)/15.82})C$	4.7
Monocropping-(R)	0	$Y = (5.63x + 35.78xe^{-(x-1)/7.52})C$	6.3	$Y = (2.22x + 15.80xe^{-(x-1)/7.51})C$	7.1
Intercropping	150	$Y = (8.15x + 17.55xe^{-(x-1)/9.39})C$	2.2	$Y = (2.15x + 7.25xe^{-(x-1)/10.81})C$	3.4
Monocropping-(I)	150	$Y = (11.52x + 48.67xe^{-(x-1)/14.37})C$	4.2	$Y = (3.06x + 18.02xe^{-(x-1)/14.65})C$	5.9
Relaycropping	150	$Y = (3.79x + 14.62xe^{-(x-1)/14.55})C$	3.9	$Y = (1.06x + 4.79xe^{-(x-1)/22.62})C$	4.5
Monocropping-(R)	150	$Y = (7.05x + 30.99xe^{-(x-1)/8.24})C$	4.4	$Y = (1.85x + 11.67xe^{-(x-1)/14.84})C$	6.3

†: Equations are in the form of $Y = [y_{ar}x + (y_o - y_{ar})xe^{-(x-1)/X_{cp}}]C$, where y_o, y_{ar}, and X_{cp} are as explained in Table 4. C is conversion factor of g $PDMAX^{-2}$ into kg ha^{-1}, where C = 10.

+: $PDMAX^{-2} = m^{-2}$.

°: $DRR = (y_o - y_{ar}):y_{ar}$.

¶: In inter- and relaycropping, equations were the representatives over three corn densities (2.7, 5.3, and 13.3 plants m^{-2}).

and ++: Indicate monocroppings that correspond to the inter- and relayplanting dates, respectively.

X_{cp} constants were 25.7, 16.6, 17.3, 20.4, and 19.4 plants $PDMAX^{-2}$. The increasing rates involved in the above trends were peanut density-dependent. With DRR and X_{cp} values of 5.0 and 13.8 plants $PDMAX^{-2}$, respectively, a steeper increase (after some gradual increase at medium density) was observed at higher density in the N-fertilized monocropping-(I) of cycle 1. The above trends were also observed in their counterpart environments in cycle 2. The findings suggest that at the respective environments, the growth per plant was not readily reduced by increasing density at the high-density region, and a significant amount of apparent residual (y_{ar}) became gradually important in determining the total peanut growth at the above region. Furthermore, with a lower competitive density constant (or faster response to increasing density), the apparent residual became dominant in determining total peanut growth at higher densities. As characterized by (a) low pH, (b) high C:N ratio, (c) low available macro- and micronutrients (Parbery and Venkatachalam, 1964; Joseph et al., 1974), (d) and poor nodulation on inoculated peanut even with high liming rate (Shamshuddin, 1984), peat would probably provide an environment that caused the positive density-dependent total peanut growth. This probably suggests that the presence rather than the size of individual plants is more important in exploiting the resources in the above environment.

The combination of differentiable portion ratio $[(y_o - y_{ar}):y_o]$ and density constant (X_{cp}) was only used as a guide in describing the shape of the TDM vs. density relationship. More importantly, the

combination of absolute values of y_{ar}, y_o, and X_{cp} were important in providing the actual prediction of the TDM vs. density relationships in a given environment. The extrapolation of the curve according to the equation or model beyond highest density range tested should only be done with caution, since the above model was developed for surviving plant density, and thus not seeding rate or density at planting. Furthermore, the average TDM yield per unit land area accumulation rate should not exceeded about 15 g m^{-2} d^{-1} for C3 crops or 25 g m^{-2} d^{-1} for C4 crops (Monteith, 1978). The arbitrary categorization (high, low, etc.) of differentiable response ratio and competitive density constant should be associated with a specific crop (peanut in this case).

Peanut Pod Yield Per Hectare Response and Model

The effects of nitrogen (N), system-corn density (S-C), and peanut density (P) on pod yield per ha were similar to the previously discussed TDM per ha data (Table 10; Figures 14, 15, 16; Appendix Table B-3). However, non-parallelisms between peanut TDM vs. density and pod yield vs. density relationships were observed, which might have been due to difference in partitioning of photoassimilate into vegetative and reproductive parts with increase in interplant competition (Duncan, 1986). The importance of N and peanut density in pod yield per ha under mono-, inter-, and relaycropping systems is greater than for TDM yield. Since pod yield in relaycropping presumably was reduced by low available N and other nutrients, and less affected by low light received during the early growth, higher

Figure 14. Relationships between peanut pod yield per ha and plant density in mono-, inter-, and relaycropping environments of Cycle 1 experimentation on a Malaysian histosol. Monocropping-(I) and monocropping-(R) indicate monocroppings that correspond to inter- and relayplanting dates, respectively. Response trends in inter- and relaycropping represent over three sweetcorn densities. $PDMAX^2 = 1.0\ m^2$. The LSD bar shown is for comparison between two system-corn density (cropping system at each corn density) yields at same nitrogen x peanut density combination. The respective values of effects and LSD bar shown are indicated in Appendix Table B-3.

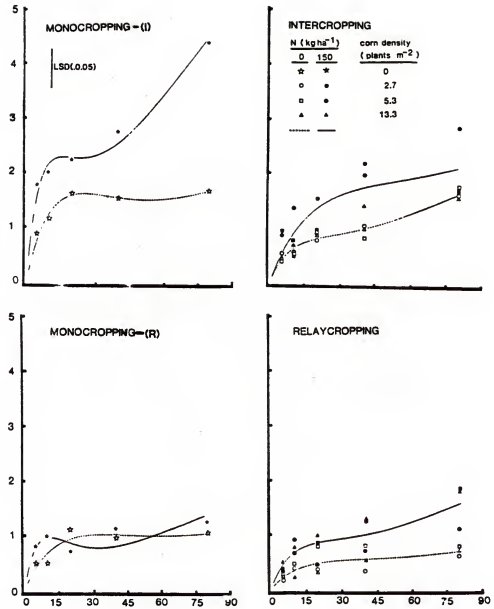

MONOCROPPING-(I)
LSD(0.05)
INTERCROPPING
N (kg ha⁻¹)
0
150
corn density
(plants m⁻²)
0
2.7
5.3
13.3
MONOCROPPING-(R)
RELAYCROPPING
POD YIELD (kg×1000 ha⁻¹)
DENSITY (plants PDMAX⁻² = plants m⁻²)
0
15
30
45
60
75
90
1
2
3
4
5

Figure 15. Relationships between peanut pod yield per ha and plant density in mono-, inter-, and relaycropping environments of Cycle 2 experimentation on a Malaysian histosol. Monocropping-(I) and monocropping-(R) indicate monocroppings that correspond to inter- and relayplanting dates, respectively. Response trends in inter- and relaycropping represent over three sweetcorn densities. $PDMAX^2 = 1.0\ m^2$. The LSD bar shown is for comparison between two system-corn density (cropping system at each corn density) yields at same nitrogen x peanut density combination. The respective values of effects and LSD bar shown are indicated in Appendix Table B-3.

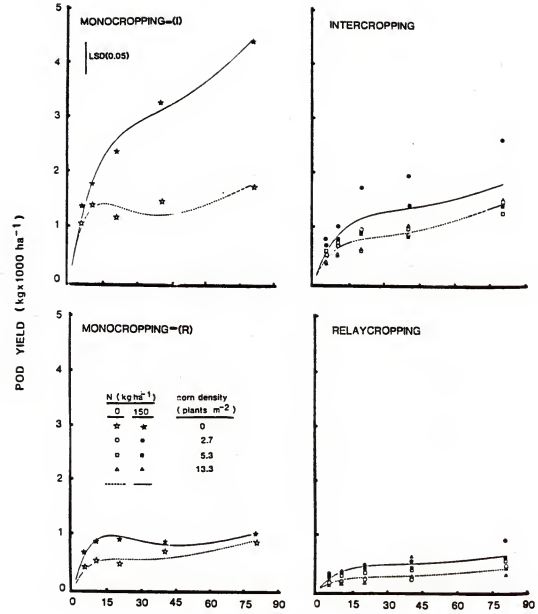
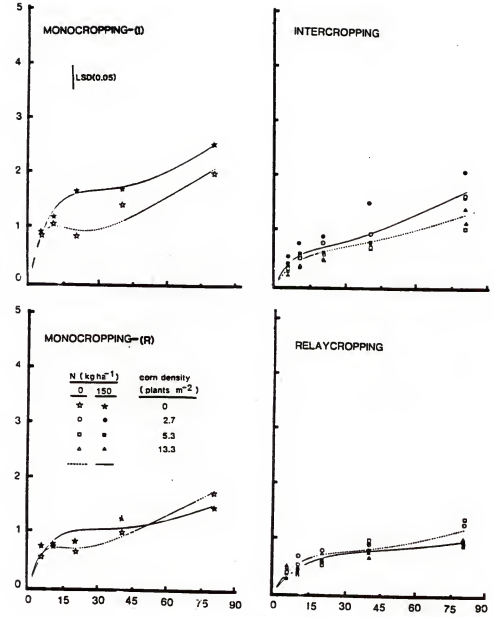

MONOCROPPING-(I)
LSD(0.05)
INTERCROPPING
MONOCROPPING-(R)
RELAYCROPPING
N (kg ha-1)
0
150
corn density
(plants m-2)
0
2.7
5.3
13.3
POD YIELD (kgx1000 ha-1)
DENSITY (plants PDMAX-2 =plants m-2)

Figure 16. Relationships between peanut pod yield per ha and plant density in mono-, inter-, and relaycropping environments of Cycle 3 experimentation on a Malaysian histosol. Monocropping-(I) and monocropping-(R) indicate monocroppings that correspond to inter- and relayplanting dates, respectively. Response trends in inter- and relaycropping represent over three sweetcorn densities. $PDMAX^2 = 1.0\ m^2$. The LSD bar shown is for comparison between two system-corn density (cropping system at each corn density) yields at same nitrogen x peanut density combination. The respective values of effects and LSD bar shown are indicated in Appendix Table B-3.


MONOCROPPING-(I)
LSD(0.05)
INTERCROPPING
MONOCROPPING-(R)
N (kg ha⁻¹)
0
150
corn density
(plants m⁻²)
0
2.7
5.3
13.3
RELAYCROPPING
POD YIELD (kg×1000 ha⁻¹)
0
15
30
45
60
75
90
DENSITY (plants PDMAX⁻²=plants m⁻²)

yield could probably be achieved by reapplying N and other required nutrients immediately after sweetcorn harvest. The data show positive responses to applied N on peanut growth and yield on tropical peat soil (Table 10; Figures 11 to 16; Appendix Table B-3).

The average pod yields in monocropping-(I), intercropping, and relaycropping of N-fertilized plots in cycle 1 were 2632, 1355, and 920 kg ha^{-1}, respectively (Figures 14, 15, and 16; Appendix Table B-3). Therefore, the average total pod yield reductions by inter- and relaycropping under N-fertilization treatment were 49 and 65%, respectively. Syarifuddin et al. (1974) reported 20 to 30% peanut yield reduction by intercropped corn at increasing density. In cycle 1, it was further shown that the respective average pod yields of the above cropping treatments without N-fertilization were 1364, 887, and 457 kg ha^{-1} (35 and 66% pod yield reduction by corn in inter- and relaycropping, respectively). Similar responses were also observed in cycles 2 and 3. Furthermore, corn densities (2.7 to 13.3 plants m^{-2}) were observed to reduce peanut yield more in N-fertilized intercropping plots of all cycles then in other N x CS environments (Figures 14, 15, and 16; Appendix Table B-3). In the other environments, the corn density effect was small to inconsistent indicating the corn presence rather than density was important in affecting non-N-fertilized intercrop, and non-N- and N-fertilized relaycrop peanut yields. Above results sugggest that low light and competition for nutrients (especially N) were main factors in reducing N-fertilized intercrop peanut yield, whereas mainly competition for

nutrients (especially N) was operative in situations of other N x CS environments.

The pod yields generally greatly increased with peanut density in the N-fertilized monocropping-(I) plots and in the N-fertilized intercropping plots with 2.7 and 5.3 plants m^{-2} of associated corn for all cycles (Figures 14, 15, and 16; Appendix Table B-3). Reported monocrop peanut yield on Malaysian peat by Chew (1978) was 1,700 to 2,040 kg ha^{-1}. Thus if corn ear yield is not badly affected by the intercrop peanut, then intercrop peanut yields at densities of 40 to 80 plants m^{-2} [depending on the corn densities (2.7 or 5.3 plants m^{-2})] were in the acceptable range as the additional component crop yields to the yields of base-corn crop in intercropping systems on this histosol environment.

Regression equations of pod yield per ha vs. density relationships are presented in Table 11 and their response curves in N x cropping system environments in all three cycles are shown in Figures 14, 15, and 16. The respective trends in inter- and relaycropping represented over the three corn densities (2.7, 5.3, and 13.3 plants m^{-2}). Asymptotic relationships were observed in the non-N-fertilized monocropping-(I) and monocropping-(R) of cycle 1. This was due to high competitive density constants (X_{cp}) (17.9 and 22.4 competitive plants $PDMAX^{-2}$ in above environments, respectively) coupled with moderately high differentiable response ratios (DRR) (9.4 and 8.3). Some responses that were initially asymptotic and thereafter increased with increasing density were also observed. In other environments where relatively medium to low DRR values coupled

with respective medium to high X_{cp} constants were obtained, the pod yield vs. density relationships showed an increasing trend. Especially with a moderately high X_{cp} (18.6 competitive plants $PDMAX^{-2}$) coupled with low DRR (4.0), the increasing trend was rather gradual in the N-fertilized monocropping-(I) of cycle 2 (Figure 15). All above results suggest that some balancing between "competition speed" or "dynamics" and plant density had resulted in a positive continuous increase in pod yield at the high-density (40 to 80 plants m^{-2}) region. The resulting curve of N-fertilized monocropping-(R) of cycle 1 (Figure 14) was probably due to the variability in the related experimental plots. The pod yield per ha vs. density model which was derived from the pod yield per plant vs. density relationship fit the data well in all three cycles of experimentation.

The highest monocropping yields on the N-fertilized highly acidic tropical peat in all three cycles were obtained from 80 plants m^{-2} and this was also predicted by the model (Figures 14, 15, and 16; Appendix Table B-3). The respective pod yields in cycles 1, 2, and 3 were 4386, 4395, and 2524 kg ha^{-1}, respectively. In the N-fertilized intercropping plots, pod yields (over three corn densities) at 80 plants m^{-2} were only slightly higher than at 20 to 40 peanut plants m^{-2} in cycles 1 and 2 (high yield was apparently at 80 plants m^{-2} in cycle 3). In the N-fertilized relaycropping plots, asymptotic and near asymptotic responses began to be reached at 20 plants m^{-2}. However, due to the predicted yield improvement if refertilized immediately after 80-day corn harvest, a density at 80 peanut

plants m^{-2} should be employed for higher total relaycropping peanut yield on this tropical peat.

Sweetcorn Total Dry Matter Yield Per Hectare Response and Model

Table 12 shows strong main effects of nitrogen (N), corn density (C), and cropping systems (CS) on sweetcorn TDM per ha in all three cycles of experimentation. The significant main peanut density effect (P) was also detected in all cycles (but with low F values). Several significant interactions among sources were also indicated in all cycles, but with generally low F values.

In all cycles, TDM yields per ha on N-fertilized plots were much higher than those of non-N-fertilized plots (Table 12; Figures 17, 18, 19; Appendix Table B-4). Joseph et al. (1974) reported only 98 ppm available mineral N (0.71% of total N) in this peat.

Table 12 shows the corn TDM yields in monocroppings were higher than those in intercroppings, but were similar to those in relaycroppings. Specifically, in the N-fertilized plots, the differences in TDM yields between mono- and intercropping were greater in cycles 1 and 3, but differed little in cycle 2 previously grown to corn (Figures 17, 18, and 19; Appendix Table B-4). Furthermore, plots of cycle 2 had highest pH after liming and lowest C:N compared to plots of cycles 1 and 2 (Table 1). Corn TDM yields from mono- and relaycropping in both N- and non-N-fertilized plots in all cycles (except at 13.3 corn plants m^{-2} of N-fertilized plot in cycle 1) were generally similar (Figures 16, 17, and 18; Appendix Table B-4). These results suggest that total corn growth was reduced by intercrop peanut

Table 12. Sweetcorn total dry matter (TDM) and ear yield per hectare as affected by nitrogen rate, cropping system, sweetcorn density, and peanut density in three cycles of experimentation on a Malaysian histosol.

Treatment	Total dry matter			Ear yield		
	Cycle			Cycle		
	1	2	3	1	2	3
	kg ha^{-1}					
Nitrogen (N)†						
0 kg ha^{-1}	1928	3813	2914	1117	2588	1839
150 kg ha^{-1}	5767	6032	5285	5861	5731	4600
LSD (0.05)	538	941	418	1627	1877	287
Cropping system (CS)†						
Intercropping (I)	3131	4544	3453	2740	3573	2223
Relaycropping (R)	4341	5206	4572	4117	4569	4027
Monocropping (M)	4971	5399	4972	4095	5048	4168
LSD (0.05)‡ I vs. R	408	329	256	343	361	296
LSD (0.05)‡ M vs. (I or R)	707	570	443	594	625	512
Corn density (C)†						
2.7 plants m^{-2}	2971	3377	2969	3424	3539	3437
5.3 plants m^{-2}	3727	4659	3992	3938	4412	3482
13.3 plants m^{-2}	4846	6733	5337	3106	4528	2741
LSD (0.05)	477	384	299	400	422	345
Peanut density (P)°						
5 plants m^{-2}	4134	5276	4126	3594	4466	3192
10 plants m^{-2}	3899	4859	4278	3477	3943	3455

20 plants m^{-2}	3911	4595	3713	3787	3721	2927
40 plants m^{-2}	3305	5092	3933	2969	4443	3036
80 plants m^{-2}	3429	4555	4012	3317	3781	3015
LSD (0.05)	504	475	390	510	464	423
			F Statistic (F value)			
N†	362.00**	28.39*	179.97**	51.51**	13.53*	520.49**
CS	21.13**	9.69**	45.24**	28.60**	19.08**	76.73**
C	26.35**	82.70**	81.25**	5.72**	10.44**	7.43**
N x CS	2.87^{+}	5.02**	3.69*	1.43^{ns}	3.89*	0.73^{ns}
N x C	17.20**	3.08*	16.97**	5.54**	8.56**	2.40^{+}
CS x C	2.50*	1.70^{ns}	1.04^{ns}	3.46**	1.08^{ns}	2.29^{+}
N x CS x C	2.49*	0.26^{ns}	1.57^{ns}	0.78^{ns}	0.41^{ns}	2.30^{+}
P°	2.88*	3.33*	2.15^{+}	1.43^{ns}	4.51**	1.49^{ns}
P x N	0.30^{ns}	2.80*	1.42^{ns}	0.38^{ns}	2.01^{+}	0.25^{ns}
P x CS	1.16^{ns}	0.58^{ns}	1.27^{ns}	0.54^{ns}	1.10^{ns}	1.54^{ns}
P x C	0.92^{ns}	0.54^{ns}	0.53^{ns}	1.20^{ns}	1.01^{ns}	0.59^{ns}
P x N x CS	1.48^{ns}	0.66^{ns}	2.62*	0.61^{ns}	1.41^{ns}	0.68^{ns}
P x N x C	1.38^{ns}	1.05^{ns}	0.68^{ns}	2.11^{+}	0.47^{ns}	0.63^{ns}
P x CS x C	2.13*	0.90^{ns}	0.63^{ns}	0.90^{ns}	1.24^{ns}	0.47^{ns}
P x CS x C x N	1.58^{ns}	0.47^{ns}	0.46^{ns}	0.95^{ns}	0.55^{ns}	0.19^{ns}

†: Due to the design employed, the ANOVA was done according to the split-plot design; main plots: N, sub-plots: CS and C.

‡: Due to the design employed, inter- and relaycropping had 120 observations each, while monocropping had only 24. Thus, two respective LSD values were used.

°: Due to the design employed (excluding corn monocropping which had no peanut density effect, and that additionally to avoid missing cell in the analysis), the ANOVA was done according to the split-split-plot design, i.e., main plots: N; sub-plots: CS and C; sub-sub-plots: P. Only F statistics of P and its related interaction effects are shown.

$^{+}$, *, **, and ns: Significant at $\alpha = 0.10$, $\alpha = 0.05$, and $\alpha = 0.01$ levels, and not significant, respectively.

Figure 17. Relationships between sweetcorn total dry matter or ear yield per ha in mono-, inter-, and relaycropping environments of Cycle 1 experimentation on a Malaysian histosol. Response trends in inter- and relaycropping represent over five peanut densities. $CDMAX^2 = 3.24$ m^2. The LSD bars shown are used for comparison in (a) †: between monocropping and mean (over five peanut densities) of inter- or relaycropping at same nitrogen x corn density combination, (b) ‡: between means of inter- and relaycropping at same nitrogen x corn density combination, and (c) °: between two peanut density yields at same nitrogen x cropping system x corn density combination (only for inter- and relaycropping). The respective values of effects and LSD bars shown are indicated in Appendix Table B-4.

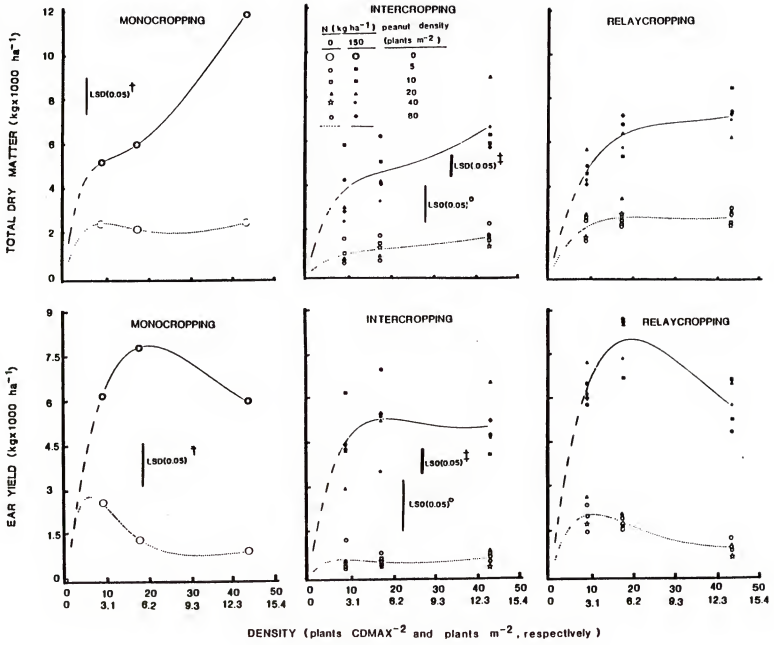

MONOCROPPING
INTERCROPPING
RELAYCROPPING
N (kg ha⁻¹)
0
150
peanut density (plants m⁻²)
0
5
10
20
40
80
LSD(0.05)†
LSD(0.05)‡
LSD(0.05)°
TOTAL DRY MATTER (kgx1000 ha⁻¹)
EAR YIELD (kgx1000 ha⁻¹)
0 10 20 30 40 50
0 3.1 6.2 9.3 12.3 15.4
DENSITY (plants CDMAX⁻² and plants m⁻², respectively)

Figure 18. Relationships between sweetcorn total dry matter or ear yield per ha in mono-, inter-, and relaycropping environments of Cycle 2 experimentation on a Malaysian histosol. Response trends in inter- and relaycropping represent over five peanut densities. $CDMAX^2 = 3.24$ m^2. The LSD bars shown are used for comparison in (a) †: between monocropping and mean (over five peanut densities) of inter- or relaycropping at same nitrogen x corn density combination, (b) ‡: between means of inter- and relaycropping at same nitrogen x corn density combination, and (c) °: between two peanut density yields at same nitrogen x cropping system x corn density combination (only for inter- and relaycropping). The respective values of effects and LSD bars shown are indicated in Appendix Table B-4.

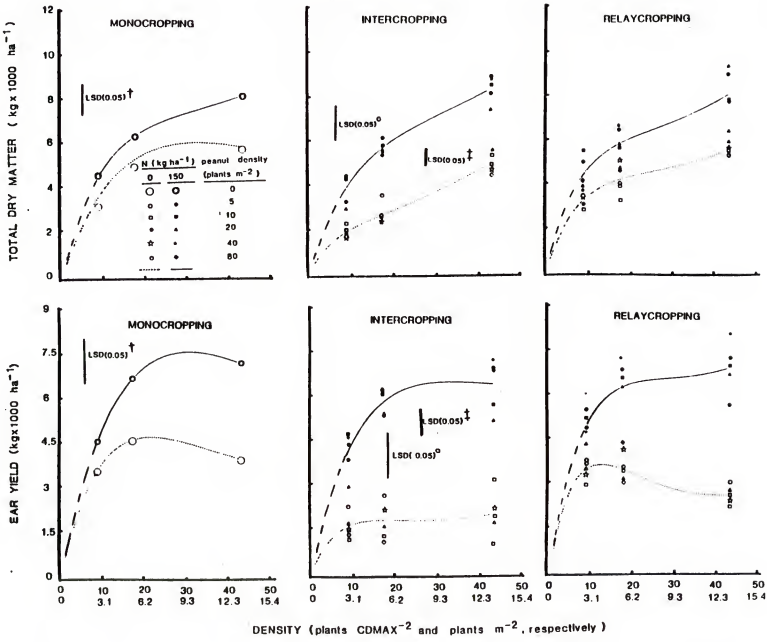
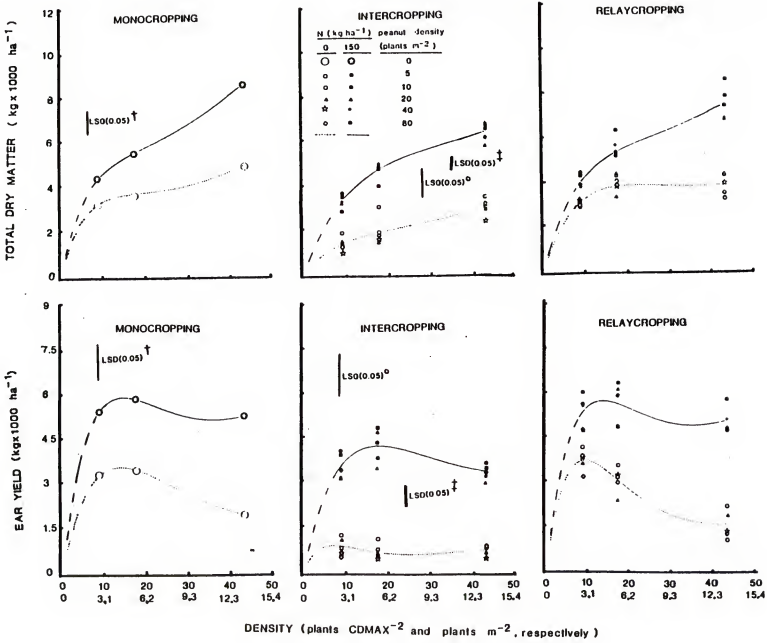

MONOCROPPING
INTERCROPPING
RELAYCROPPING
TOTAL DRY MATTER (kg x 1000 ha⁻¹)
EAR YIELD (kg x 1000 ha⁻¹)
LSD(0.05)†
LSD(0.05)°
LSD(0.05)‡
N (kg ha⁻¹)
0
150
peanut density (plants m⁻²)
0
5
10
20
40
80
DENSITY (plants CDMAX⁻² and plants m⁻², respectively)

Figure 19. Relationships between sweetcorn total dry matter or ear yield per ha in mono-, inter-, and relaycropping environments of Cycle 3 experimentation on a Malaysian histosol. Response trends in inter- and relaycropping represent over five peanut densities. $CDMAX^2 = 3.24$ m^2. The LSD bars shown are used for comparison in (a) †: between monocropping and mean (over five peanut densities) of inter- or relaycropping at same nitrogen x corn density combination, (b) ‡: between means of inter- and relaycropping at same nitrogen x corn density combination, and (c) °: between two peanut density yields at same nitrogen x cropping system x corn density combination (only for inter- and relaycropping). The respective values of effects and LSD bars shown are indicated in Appendix Table B-4.


MONOCROPPING
INTERCROPPING
RELAYCROPPING
TOTAL DRY MATTER (kg x 1000 ha⁻¹)
EAR YIELD (kg x 1000 ha⁻¹)
N (kg.ha⁻¹)
0
150
peanut density (plants m⁻²)
0
5
10
20
40
80
LSD(0.05)†
LSD(0.05)‡
LSD(0.05)°
0 10 20 30 40 50
0 3,1 6,2 9,3 12,3 15,4
DENSITY (plants CDMAX⁻² and plants m⁻², respectively)

which apparently competed for the edaphic growth factors, particularly in the non-N-fertilized plots. However, due to short overlapping period (practically only 12 to 19 days) between peanut and corn, relaycrop peanut competition to corn growth was insignificant.

Within the intercropping environment, the general trend of corn TDM reductions by increased peanut densities in N-fertilized plots were more obvious in plots of high C:N ratio (cycle 1), but were inconsistent in the other two cycles (Figures 17, 18, and 19; Appendix Table B-4). In non-N-fertilized intercropping plots, corn TDM yields per ha were consistently reduced (although with small reduction) at 10 to 80 peanut plants m^{-2} in all three cycles compared to lower peanut densities. These suggest that the presence of intercrop peanut was important in reducing corn growth, whereas additional general reductions by increased peanut densities (5 to 80 plants m^{-2}) were pronounced only in the N-fertilized soil of high C:N (cycle 1) and in non-N-fertilized soil of all cycles regardless of C:N ratios. Inconsistent or inconsequential relaycrop peanut-density effects were observed under all N x corn density situations in relaycropping plots in all cycles (Figures 17, 18, and 19; Appendix Table B-4). This strengthened the conclusion of no or little effect of relayplanted peanut on the corn growth.

Equations of TDM per ha vs. density relationships are shown in Table 13. Response trends grouped by CS and N are presented in Figures 17, 18, and 19.

Table 13. Equations† of sweetcorn total dry matter (TDM) and ear yield per hectare (Y) against corn density (x) for $1 \leq x \leq 43.1$ plant $CDMAX^{-2}$ and differentiable response ratio (DRR) under nitrogen x cropping system environments in three cycles of experimentation on a Malaysian histosol.

System	Nitrogen (kg ha^{-1})	TDW ha^{-1} Equation	DRR°	Ear yield ha^{-1} Equation	DRR°
		Cycle 1			
Intercropping	0	$Y = (11.90x + 44.65xe^{-(x-1)/10.64})C$	3.8	$Y = (4.58x + 55.86xe^{-(x-1)/6.57})C$	12.2
Relaycropping	0	$Y = (15.67x + 120.75xe^{-(x-1)/12.95})C$	7.7	$Y = (4.99x + 159.55xe^{-(x-1)/9.44})C$	31.9
Monocropping	0	$Y = (17.42x + 203.53xe^{-(x-1)/7.39})C$	11.7	$Y = (6.36x + 355.24xe^{-(x-1)/5.56})C$	55.8
Intercropping	150	$Y = (47.65x + 205.83xe^{-(x-1)/9.83})C$	4.3	$Y = (28.43x + 253.63xe^{-(x-1)/12.8})C$	8.9
Relaycropping	150	$Y = (38.18x + 222.57xe^{-(x-1)/16.18})C$	5.8	$Y = (10.56x + 343.80xe^{-(x-1)/17.82})C$	32.6
Monocropping	150	$Y = (88.30x + 389.20xe^{-(x-1)/5.78})C$	4.4	$Y = (14.34x + 332.83xe^{-(x-1)/17.54})C$	23.2
		Cycle 2			
Intercropping	0	$Y = (36.57x + 77.63xe^{-(x-1)/9.06})C$	2.1	$Y = (12.92x + 94.22xe^{-(x-1)/10.58})C$	7.3
Relaycropping	0	$Y = (36.30x + 159.01xe^{-(x-1)/12.27})C$	4.4	$Y = (15.20x + 239.28xe^{-(x-1)/10.33})C$	15.8
Monocropping	0	$Y = (10.40x + 163.34xe^{-(x-1)/26.69})C$	15.7	$Y = (11.98x + 182.83xe^{-(x-1)/17.94})C$	15.3
Intercropping	150	$Y = (51.07x + 145.62xe^{-(x-1)/16.54})C$	2.9	$Y = (23.18x + 186.06xe^{-(x-1)/20.77})C$	8.0
Relaycropping	150	$Y = (53.80x + 206.83xe^{-(x-1)/12.31})C$	3.8	$Y = (39.22x + 248.72xe^{-(x-1)/13.95})C$	6.3
Monocropping	150	$Y = (44.49x + 190.76xe^{-(x-1)/16.79})C$	4.3	$Y = (8.24x + 210.06xe^{-(x-1)/27.52})C$	25.5

		Cycle 2		Cycle 3	
Intercropping	0	$Y = (21.10x + 55.29xe^{-(x-1)/11.77})C$	2.6	$Y = (5.48x + 92.32xe^{-(x-1)/6.16})C$	16.8
Relaycropping	0	$Y = (20.98x + 160.94xe^{-(x-1)/13.90})C$	7.7	$Y = (8.89x + 313.93xe^{-(x-1)/8.62})C$	35.3
Monocropping	0	$Y = (33.90x + 185.74xe^{-(x-1)/9.57})C$	5.5	$Y = (6.92x + 206.04xe^{-(x-1)/12.72})C$	29.8
Intercropping	150	$Y = (37.38x + 132.92xe^{-(x-1)/16.99})C$	3.5	$Y = (14.38x + 200.44xe^{-(x-1)/14.39})C$	13.9
Relaycropping	150	$Y = (49.08x + 175.44xe^{-(x-1)/13.14})C$	3.6	$Y = (31.52x + 348.50xe^{-(x-1)/10.46})C$	11.1
Monocropping	150	$Y = (60.93x + 213.28xe^{-(x-1)/9.92})C$	3.5	$Y = (32.20x + 340.22xe^{-(x-1)/10.94})C$	10.6

†: Equations are in the forms of $Y = [y_{ar}x + (y_o - y_{ar})xe^{-(x-1)/X_{cc}}]C$, where y_o, y_{ar}, and X_{cc} are as explained in Table 8. C is conversion factor of g $CDMAX^{-2}$ into kg ha^{-1}, where C = 10/3.24.

+: $CDMAX^2 = (1.8\ m)^2 = 3.24\ m^2$.

°: $DRR = (y_o - y_{ar}):y_{ar}$.

The TDM per ha vs. density relationships within the experimental density range with N fertilization exhibited increasing responses at high-density regions for each treatment and each cycle (Figures 17, 18, and 19). These responses were associated with low differentiable response ratios (DRR) (Table 13), and a range of density constants (X_{cc}) from 5.8 to 17.0 competitive corn plants $CDMAX^{-2}$. Particularly, with a low density constant (5.8 plants $CDMAX^{-2}$), as shown in monocropping of cycle 1, the increase was steeper at the high-density region (Figure 17). On the other hand, with moderately high DRR (5.8) that coupled with high X_{cc} (16.2 plants $CDMAX^{-2}$), the relationship was near asymptotic within the experimental density range in the relaycropping of cycle 1. In the N-fertilized peat environment, corn growth generally increased with density (surviving plant per m^2) in all cropping system treatments (except for the asymptotic increase in relaycropping treatment of cycle 1). The increase was greater if the typical low DRR (moderately high y_{ar} with $y_{ar} < y_o$) was coupled with a low X_{cc} (faster reaction).

Under the non-N-fertilized environment, the increasing trend responses of sweetcorn TDM per ha vs. density relationships were observed in several croppings associated with low values of DRR (2.1 to 5.5) and moderate values of X_{cc} (9.1 to 12.3 plants $CDMAX^{-2}$). The relationships in relaycropping plots of cycles 1 and 3, and monocropping of cycle 1 were asymptotic (DRR: 7.7 and 7.7 for cycles 1 and 3, respectively; X_{cc}: 12.9 and 13.9 competitive plants $CDMAX^{-2}$), and near asymptotic (DRR: 11.7; X_{cc}: 7.4 competitive

plants $CDMAX^{-2}$), respectively (Figures 17 and 18). The relationship of TDM per ha vs. density in non-N-fertilized monocropping of cycle 2 was about parabolic (near asymptotic) (DRR: 15.7; X_{cc}: 26.7 plants $CDMAX^{-2}$).

The above discussion suggests that the effects of corn density on corn TDM under N- and non-N-fertilized histosol soil were influenced by cycle (or location) and cropping system environment.

Sweetcorn Ear Yield Per Hectare Response and Model

Table 12 shows strong main effects of nitrogen (N), cropping systems (CS) and corn density (C) on sweetcorn ear yield per ha. Some significant interactions among above sources on ear yields per ha were also indicated in all cycles, but with low F values compared to the F values of the above main effects (Table 12).

Table 12 shows that average ear yields per ha in N-fertilized plots were significantly higher than those in non-N-fertilized treatments for all cycles, hence N-fertilization was an important factor in the sweetcorn ear yield production on this Malaysian histosol.

Figures 17, 18, and 19, and Appendix Table B-4 show that the N- and non-N fertilized monocropping treatments produced generally higher ear yields than those from the intercropping plots in all cycles. Previous cropping history (e.g., cassava) appeared to have some effect (cycle differences) on sweetcorn ear yield. Figures 17, 18, and 19, and Appendix Table B-4 show that there were generally little or no differences between mono- and relaycropping ear yields per ha in both N- and non-N fertilized plots in all cycles. Increasing peanut

density (especially at 2.7 and 5.3 corn plants m^{-2}) appeared to cause some reduction in intercropping corn ear yields per ha in the higher C:N plots (cycles 1 and 3) and in the non-N-fertilized plots (even though with smaller reduction) regardless of the C:N values (Figures 17, 18, and 19; Appendix Table B-4).

In averaging over corn and peanut densities, the average corn ear yields of N-fertilized mono-, inter-, and relaycropping in cycle 1 were 6617, 4912, and 6660 kg ha^{-1}, respectively (26% and 0% corn ear yield reductions by inter- and relayplanted peanut, respectively). Furthermore, in the non-N-fertilized plots, the ear yields of mono-, inter-, and relaycropping were 1572, 569, and 1574 kg ha^{-1}, respectively (64% and 0% reductions by inter- and relayplanted peanut, respectively). The above trends were similar to those in cycles 2 and 3. Calculation from data of the 1972 study reported by Beste (1976) shows that sweetcorn ear yield was reduced by 20 to 72% when cocropped with soybean of different densities. Davis and Garcia (1983) indicated grain yield reduction by 15 to 30% when intercropped with beans, but there was no reduction in relaycropping. Knauft (1984) showed that the reduction of corn yield by intercrop peanut was 32 to 38%.

The corn ear yield per ha vs. density equations, which are equivalent to those of corn ear yield per plant vs. density relationships (Table 8) by means of transform function (Y = yxC), are given in Table 13. The relationship curves grouped by N and CS are presented in Figures 17, 18, and 19.

The corn ear yield per ha vs. density relationships in N-fertilized (cycle 1) and non-N-fertilized (cycles 1 and 3)

monocroppings, and non-N-fertilized relaycroppings (cycles 1 and 3) were parabolic. This was primarily due to very wide differentiable response ratios (DRR) (23.2 to 35.3) coupled with the competitive density constants (X_{cc}) ranging from 5.5 to 17.8 competitive corn plants $CDMAX^{-2}$. The faster response (lower X_{cc}) (5.5 plants $CDMAX^{-2}$) in the non-N-fertilized monocropping of cycle 1 caused the optimum ear yield to be at lower corn plant density (5.7 plants $CDMAX^{-2}$ or 1.8 plants m^{-2}) as compared at higher density (19.7 plants $CDMAX^{-2}$ or 6.1 plants m^{-2}) in the N-fertilized plot. Furthermore, low X_{cc} (5.5 competitive plants $CDMAX^{-2}$) coupled with extremely wide DRR (55.8) (as in non-N-fertilized monocropping of cycle 1) resulted in a long-flattened tail of the parabola at increasing density (Figure 17). The moderately wide DRR values (10.6 to 15.8) coupled with medium to moderately high X_{cc} (10.3 to 17.9 competitive plants $CDMAX^{-2}$) caused the ear yield vs. density relationships to be about parabolic in the other N x CS environments (Figures 17, 18, and 19). The asymptotic relationships were observed in N- and non-N-fertilized intercroppings, and N-fertilized relaycropping of cycle 2 (Figure 18). The above findings suggest that the parabolic or near parabolic ear yield vs. density relationships were found in most of the environments within density ranges employed in all cycles. The non-N-fertilized plots had lower optimum and beginning-asymptotic phase densities compared to those in the N-fertilized treatments (Figures 17, 18, and 19). Duncan (1958) indicated that increasing N increased the number of plants needed for maximum yield. Above results suggest that relative

resource utilization (used/readily available) at lower corn density in non-N-fertilized plots was higher than that in N-fertilized plots for corn ear development.

From the equations (based on the proposed model) and trends shown in Table 13 and Figures 17, 18, and 19, the optimum corn densities of N-fertilized intercroppings in cycles 1, 2, and 3 were 18.4, 32.6, and 17.7 plants $CDMAX^{-2}$ (5.7, 10.1, and 5.5 plants m^{-2}), respectively, whereas in the N-fertilized relaycroppings, the respective optimum densities were 19.3, 27.9, and 13.6 plants $CDMAX^{-2}$ (5.9, 8.6, and 4.2 plants m^{-2}). Furthermore, the optimum densities of N-fertilized monocroppings in cycles 1, 2, and 3 were 19.7, 30.7, and 14.5 plant $CDMAX^{-2}$ (6.1, 9.5, and 4.5 plants m^{-2}), respectively. In cycle 2, the ear yield vs. density curves in inter-, relay-, and monocropping were near parabolic, asymptotic, and asymptotic, respectively. The yields of above croppings at their respective optimum densities (10.0, 8.3, and 9.5 plants m^{-2}) were not far from those of respective 5.3 plants m^{-2}, since the observations of these densities are at the tops of the near parabolic or asymptotic curves. All the above findings suggest that optimum densities obtained from mono-, inter-, and relaycropping plots were not far from that normally used (5.3 plants m^{-2}) (Lee et al., 1983) in growing the sweetcorn cv 'Thaisupersweet' under Malaysian conditions. Fery and Janick (1971) indicated that densities between 3.8 and 7.6 plant m^{-2} were needed for high total ear yields (about 9500 kg ha^{-1}) of sweetcorn cv. 'Golden Beauty' grown in square planting pattern.

Model and Parameter Emphases

The TDM or reproductive yield per unit area (Y) vs. density (x) relationship model [$Y = (y_{ar}x + (y_o - y_{ar})xe^{-\frac{(x-1)}{X_c}})C$ for $x \geq 1$] which had been theoretically developed from TDM or yield per plant (y) vs. density model [$y = y_{ar} + (y_o - y_{ar})e^{-\frac{(x-1)}{X_c}}$ for $x \geq 1$] was in agreement in usage with all experimental data in all environments (nitrogen x cropping system) in three cycles. Therefore the dynamics of the individual plants were directly related to the collective performance of all plants in a specific environment. The parameters, y_{ar}, y_o, and X_c, and the postulation of proportionality in plant response reduction relative to competitive plant density ($\frac{dy}{dx_c}$, where $x_c = x - 1$) to the differentiable portion per plant ($y - y_{ar}$), are important in determining the TDM or reproductive yield per unit area vs. density relationship (either parabolic, asymptotic, or an increasing trend). From several experimentations or possibly from some scientific procedures or methods, y_{ar}, y_o, X_c, and DMAX for a crop in a given environment could be determined. The parameters can also be estimated from planting a crop at the least of three planting densities (at low, near optimum, and high densities). However, four or more planting densities should provide higher precision of the parameter estimates. Duncan (1958) and Bleasdale (1967) indicated that only two densities were adequate in estimating parameters (a and b) from yield per plant vs. density relationships which in the forms of $y = a10^{bx}$ and $y^{-1} = a + bx$, respectively. However, the danger of using two points (difference between calculated maximum and

experimental treatment yields) was indicated by Willey and Heath (1970).

The parameters (y_{ar}, y_o, and X_o) are expressed in terms that are directly (biologically) related to the per plant basis [e.g., g plant^{-1} (for y_{ar} and y_o) and plants DMAX^{-2} (for X_o)], rather than abstract units. In comparisons, the parameters of polynomial models, especially at higher order, are difficult to comprehend biologically relative to crop growth and yield (Willey and Heath, 1970). Furthermore, many other models were developed from the empirical activity only, but without any biological considerations. In reviewing crop yield vs. plant population relationships, Willey and Heath (1970) indicated the identicallity of and biological meaningfulness of constants in asymptotic yield vs. density reciprocal equations ($\frac{1}{y} = a + bx$ or $Y = \frac{x}{a + bx}$) as proposed by several workers. Normally, the constants (a and b) are presented in their original forms (without taking their reciprocals), i.e., values of much less than 1. For example, Willey and Heath (1970) showed that the values of a and b for three onion varieties were 0.01117 to 0.01901 and 0.00263, respectively. By observation, it is clear that the above values are difficult to comprehend relative to their significance in plant growth or yield as related to increasing density. An exponential model is another method that is frequently used in relating yield per plant with density. In $y = a10^{-bx}$, Duncan (1958) indicated that a and b are the intercept on y axis and the slope (value of < 0) of log yield per plant vs. density relationship, respectively, where greater slope

indicates maximum yield at its lower density. In $Y = xab^x$, Carmer and Jackobs (1965) indicated that ab was yield of one plant when x = 1. They further showed that the value of a and b that related to shelled corn per hill for 8 corn hybrids were 0.673 to 1.067 and 0.798 to 0.906, respectively. In $y = y_o e^{EC}$ (as previously discussed), Duncan (1984) showed that E is always negative [log y - log y_o at unit crowding (C)], and y_o is yield per plant at zero crowding. All above discussion indicates some areas of difficulty in interpreting the significance of parameters contained in the previous models directly to the plant response vs. density relationships.

By using reciprocal or exponential models, the total yield per unit area vs. density relationships have been conditioned to either be asymptotic or parabolic. Another relationship is the increasing trend. On the other hand, even though not emphasized, the data shown by Fery and Janick (1971) indicated three phases of increase in total top weight with densities for two corn cultivars (Ohio W64 and Golden Beauty). The phases were rapid increase, then followed by a plateau phase and again with increasing trend but at lower increase rates. A similar trend was indicated by Williams et al. (1965) in a study of vegetative growth of corn as affected by population density (TDM yield at about 58 DAP). The above trends were also shown in Figures 11 and 17 (peanut and corn TDM yields, respectively, of N-fertilized monocroppings). Mathematically, the above trends do not fit to either asymptotic or delay-parabolic. Are these due to experimental error or inappropriateness of the chosen model? Based on the above discussion and in trying to answer the above question, the TDM or reproductive

yield per unit area vs. density relationship should probably be best explained by the dynamics of individual plants as affected by increasing density in rather "open" plant response vs. density. In this study, open refers to (a) some apparently minimum quantity of yield per plant (y_{ar}) at high density which depends on crop and environment; (b) plant begins to compete at some distance of separation (DMAX), otherwise if not within that distance, the TDM or reproductive yield per plant (y_o) will be constant; (c) plant density should be referred as surviving plants until maturity per competitive area ($DMAX^2$) (plant-type dependent density); and (d) yield per plant will initially be easily reduced by competitive plants, thereafter, i.e., as plant size becomes smaller, additional plants will result in less reduction in plant size [related to competitive density constant (X_o)]. It is felt that the above exponential and reciprocal models which have been previously proposed are rather "fixed." Except Duncan (1984), other workers considered density as plant number within a specified unit area (m^2, cm^2, ft^2, etc.). Even though some workers indicate that the response (TDM or reproductive yield) per plant will only be affected at the beginning of competition, the exponential or reciprocal models [except $y = y_o e^{EC}$ (Duncan, 1984)] used by them are still reflecting highest response per plant at density near zero or at "zero," while the response [also indicated by (Duncan, 1984)] approaches zero at very high density (infinity). The above indicates that response per plant reduction has to follow along the line of from highest response at density near or equal to zero to about zero response at density infinity, where density used is not plant-type

dependent but rather chosen-dimension dependent. Practically speaking, in order for the plant to survive until maturity, it should have some minimum complete structure and be capable of extracting nutrients and using other growth factors in a given environment, and thus its size is not near zero at very high density.

CHAPTER III

COMPETITION, ENVIRONMENTAL DIFFERENTIATION AND EFFICIENCY INDICES IN PEANUT AND SWEETCORN INTER- AND RELAYCROPPING SYSTEMS AS AFFECTED BY NITROGEN FERTILIZATION ON A TROPICAL HISTOSOL

Introduction

Multiple cropping has long been recognized as a common practice throughout the developing tropics (Willey, 1979b). There are numerous reports indicating the biological advantages over monoculture system. Several methods or indices for measuring competition among component crops have also been proposed (Willey, 1979a, 1979b).

In quantifying competition, the relative crowding coefficient as proposed by de Wit (1960) has been widely used in ecological research (Willey and Rao, 1980). In a given species, the above basically compares actual yield per plant in a mixture with its expected yield. Thus, it indicates the degree of intercrop competition relative to sole crop rather than between- or intercrop competition (Willey and Rao, 1980). Based on the absolute increases and decreases in component crop yields between mixtures (each species being at its equivalent in density and area of monoculture) and monocultures, McGilchrist (1965) proposed "competitive advantage of one species over the other" and "competitive depression of the other species in a mixture." His method assumed that the absolute magnitudes of increase and decrease in the diallel design experiment were approximately the same. However, this approximate equality is shown to occur only if

monoculture yields do not differ from each other appreciably (van den Bergh, 1968). McGilchrist and Trenbath (1971) revised "competitive advantage" and "competitive depression" concepts that led to the proposal of "index of apparent mutual stimulation or inhibition" and aggressivity. If aggressivity equals to zero, then both species in the mixture are said to be equally competitive.

The above competition quantifications are assumed for mixtures from a replacement series, i.e., mixtures that are formed by replacing a proportion of one species with an equivalent proportion of another species. However several studies (Kassam, 1973; IRRI, 1974; Baker and Yusuf, 1976; ICRISAT, 1977; Willey, 1979b) showed that where intercropping gave a yield advantage, the total density optimum was higher than that of either sole crop. Higher total population of a mixture of different component crops might exploit or use resources more efficiently (Willey, 1979b; Spitters, 1983a). Thus, the quantification of competition among component crops based on an additive series is evidently becoming important compared to one based on a replacement series.

Willey and Rao (1980) proposed a competitive ratio which was developed basically from the aggressivity concept of McGilchrist and Trenbath (1971). The competitive ratio measures the relative number of times by which one component crop is more competitive than the other. In bean-maize intercropping studies, Davis and Garcia (1983) used the maize yield reduction as an index of the competitive ability of bean varieties in association, as determined from linear regression

computations of yields of maize vs. the yields of different bean cultivars.

Since plant density is the governing factor in specifying crop mixtures for multiple cropping at a given environment, and since competition is always directly related to plant density (Duncan, 1984), it is reasonable to express competition in terms of plant number equivalency between component crops in giving the same effect of each crop. This concept is not shown in the above competitive ratio and index of the competitive ability. The plant number equivalency concept is easier to interpret compared to the previously discussed quantifications (Spitters, 1983a).

In consideration of the above equivalency approach, Donald (1963) proposed equivalence factors for each species in the mixtures, and the product of those factors was used as the competition index. However, he stressed that a separate analysis was needed for determining per plant yield vs. density curve of pure culture, and as such the equivalency was then predicted. Two points that might cause this method to be "inconsistent" are (a) the model used for yield vs. density relationship in pure culture might not be biologically based, and (b) "actual" plant number of one species is equated to the "predicted" plant number of the other, thus these two different bases might yield greater equivalency error. Spitters (1983a) proposed ratio of the competition coefficients which basically also used plant number equivalency concept. In contrast to the method used by Donald (1963), Spitters (1983a) used only one equation for each species, i.e., he employed a multiple regression equation of total dry weight

per plant of one species to densities of both species in the mixture, in obtaining the above equivalency. In the above computation, Spitters (1983a) used a reciprocal model, a type which is widely used in the plant response vs. density studies. In quantifying the above equivalency with respect to marketable yield, Spitters (1983b) used the model that was developed from the combination of total dry matter (TDM) per plant vs. density and harvest index vs. TDM per plant relationships. Both relationships were in the form of reciprocal models, but as indicated in Chapter II, the reciprocal model appears to have some inadequacies. Similar to the approach, but based on the biologically based plant response vs. density model of Chapter II, the competition indices of peanut and sweetcorn in association were quantified in this study.

Spitters (1983a) obtained niche differentiation between maize and peanut in association by taking ratio in plant equivalency (1 maize:n peanut) in affecting TDM per plant of peanut to that of maize. The regression constants obtained from the multiple linear regression equation from the reciprocal of TDM per plant of each crop to both component crop densities were used in determining the above respective plant equivalencies. With a similar approach to the above, but with different emphasis and model, the environmental differentiation index of peanut-sweetcorn association was then computed in this study. Peanut and sweetcorn competitive density constants (in competitive plants per $DMAX^2$, where DMAX is the distance at which intraspecific competition exists, as described in Chapter II) which have a biological basis were used in the environmental differentiation index

determination. As these competitive density constants are also revealed to be related to the manner of resource exploitation in a given environment, the degree of environmental differentiation between peanut and sweetcorn in association could then be indicated.

In assessing the efficiency (also frequently interpreted as the biological efficiency) of multiple cropping farming, the land equivalent ratio (LER) is commonly used (IRRI, 1974; Beste, 1976; Cunard, 1976; Willey, 1979a; Mead and Willey, 1980; Rao and Willey, 1980; Searle et al., 1981; Ahmed and Rao, 1982; Beets, 1982; Knauft, 1984; Manson et al., 1986; Hiebsch and McCollum, 1987). This may be defined as the relative land area under sole crops that is required to produce the yields achieved in intercropping (Willey, 1979a). Other methods used to quantify multiple cropping efficiency include relative yield total (RYT) (de Wit and van den Bergh, 1965), crop intensity index (CII) (Menegay et al., 1978), and area-time equivalency ratio (ATER) (Manson et al., 1986; Hiebsch and McCollum, 1987). The RYT is similar to LER, except that yield per plant rather than yield per unit area is used in determining RYT. The CII is developed to assess the actual area-time devoted to crop production with the total area-time available to a farmer or group of farmers during a specified time period, usually one year (Menegay et al., 1978). The ATER, which is defined as the ratio of area-time required in monoculture to area-time used by the intercrop in producing the same quantities of all component crops, is basically similar in form to LER, except that the time element is included in the ATER calculation (Hiebsch and

McCollum, 1987). If the time element is critical in the production system, ATER is a very useful method in comparing treatments that consist of inter- and relaycropping systems.

The LER values of peanut-corn associations on nonpeat soils have been reported by several workers (Mutsaers, 1978; Edje, 1980; Spitters, 1983a; Knauft, 1984). However, the above efficiency values are still lacking, especially for peanut-sweetcorn association on the Malaysian tropical peat. Apart from the pineapple (Tay and Wee, 1972) and oil palm (Jipelos et al., 1979) which are the number one and two crops in importance, respectively, on Malaysian peat, various multiple cropping systems have long been traditionally practiced by the farmers in the region. Peanut is one of the suitable component crops in multiple cropping on the above soil environment (Jipelos et al., 1979). The 75- to 80-day sweetcorn (C4) cv. Thaisupersweet which has better taste and sweetness, and similar ear yield compared to the other local cultivars (KBI, Bakti, Peat, and Manis) (Lee et al., 1983), is theoretically suitable as the other component crop (base crop) in combination with peanut (C3) in a tropical peat environment. Both LER and ATER should be useful methods for assessment of association efficiencies of peanut and sweetcorn. Since the Malaysian peat is uniquely characterized by the high C:N (Parbery and Venkatachalam, 1964; Joseph et al., 1974) and high acidity which may then reduce peanut nodulation (Shamshuddin, 1984), the assessments therefore should be subjected to different levels of N fertilization.

The objectives of this study were

(a) to determine the competition and environmental differentiation indices in peanut and sweetcorn inter- and relaycropping systems as affected by N fertilization on a Malaysian histosol and

(b) to determine the LER and ATER (with respect to TDM and reproductive yields) of the above cropping systems as affected by N fertilization and plant densities under the above histosol conditions.

Materials and Methods

Experimental Techniques

The experiment was carried out at the Integrated Peat Research Station of the Malaysian Agricultural Research and Development Institute (MARDI) in three cycles during 1985 and 1986. The experimental settings and cultural practices were described in the Materials and Methods of Chapter II. In deriving the competition, environmental differentiation, and biological efficiency indices of the peanut and sweetcorn inter- and relaycropping, the theoretical considerations and equations are presented below.

Competition Index

Spitters (1983a) estimated intraspecific competitive stress as the ratio b_1/b_o from the following equation,

$$\frac{1}{y} = b_o + b_1 x \qquad (34)$$

where y and x are biomass weight per plant and plant density, respectively, while b_o and b_1 are regression constants (intercept and slope, respectively). Furthermore, he indicated that interspecific competition effect can be computed from mutliple linear regression, which is written as

$$\frac{1}{y_1} = b_{1.0} + b_{1.1}x_1 + b_{1.2}x_2 \qquad (35)$$

where y_1, x_1, and x_2 are biomass per plant of species 1, species 1 density and species 2 density, respectively, whereas $b_{1.0}$, $b_{1.1}$, and $b_{1.2}$ are regression constants. He stated that x_2 was additive [Eq. (35)] in affecting $\frac{1}{y_1}$. The $b_{1.2}$ quantifies the interspecific competition effect. From Eq. (35), the equivalency of species 2 to species 1 in giving equal effect on $\frac{1}{y_1}$ can be quantified. Therefore, one plant of species 1 is equivalent to $b_{1.1}/b_{1.2}$ plants of species 2 with respect to $\frac{1}{y_1}$.

The above concepts and approaches were applied to the response per plant vs. density model [Eq. (22) of Chapter II] which was developed based on biological and agronomic considerations in this study. Equation (22) was originally expressed as

$$y = \begin{cases} y_o & ; \ 0 < x \leq 1 \\ y_{ar} + (y_o - y_{ar})e^{-\frac{(x-1)}{X_c}} & ; \ x \geq 1 \end{cases}$$

where y, y_o, y_{ar}, x, and X_c are as previously described in

Chapter II. Rearrangement of Eq. (22) for $x \geq 1$ into the logarithmic form suitable for linear regression yields

$$\text{Ln}(y - y_{ar}) = \text{Ln}(y_o - y_{ar}) - \frac{(x - 1)}{X_c} \tag{36}$$

Substituting $y = y_p$, $y_{ar} = y_{arp}$, $x_{cp} = x - 1$, $X_c = X_{cp}$, and $\text{Ln}(y_o - y_{ar}) = k_p$ into Eq. (36) yields

$$\text{Ln}(y_p - y_{arp}) = k_p - \frac{x_{cp}}{X_{cp}} \tag{37}$$

where subscript p refers to peanut. Addition of corn plants (x_{cc}) into peanut competitive area ($PDMAX^2$), which is postulated to be additive negatively in affecting $\text{Ln}(y_p - y_{arp})$ or natural logarithm of net differentiable response, will expand Eq. (37) into the multiple linear regression which can be expressed as

$$\text{Ln}(y_p - y_{arp}) = k'_p - \frac{x_{cp}}{X'_{cp}} - \frac{x_{cc}}{X'_{cc}} \tag{38}$$

where k'_p, X'_{cp}, and X'_{cc} are new constants, and x_{cc} was expressed as corn plants $PDMAX^{-2}$. Rearrangement of Eq. (38) into more convenient form yields

$$y_p = y_{arp} + k''_p e^{-\left(\frac{x_{cp}}{X'_{cp}} + \frac{x_{cc}}{X'_{cc}}\right)} \tag{39}$$

where k''_p and X'_{cc} are new constant and competitive corn density constant (based on $PDMAX^2$) as related to the inter- or relayplanted peanut, respectively. The X'_{cc} can be used in measuring interspecific competition effect of corn to peanut. Partially differentiating Eq. (39) with respect to x_{cp} and x_{cc} separately yields

$$\frac{\partial y_p}{\partial x_{cp}} = -\frac{k''_p}{X'_{cp}} e^{-\left(\frac{x_{cp}}{X'_{cp}} + \frac{x_{cc}}{X'_{cc}}\right)} \tag{40}$$

and

$$\frac{\partial y_p}{\partial x_{cc}} = -\frac{k''_p}{X'_{cc}} e^{-\left(\frac{x_{cp}}{X'_{cp}} + \frac{x_{cc}}{X'_{cc}}\right)} \tag{41}$$

From the ratios of the partial derivatives of Eqs. (40) and (41), it can be said that one competitive peanut plant is equivalent to X'_{cc}/X'_{cp} competitive corn plants in giving equal effect on response per plant of peanut (y_p) in the respective inter- or relaycropping system. This plant equivalency is then defined as the competition index of corn to peanut ($CI_{c \text{ to } p}$). However, if the interaction in $Ln(y_p - y_{arp})$ between x_{cp} and x_{cc} is present, then Eq. (38) can be expanded into new multiple linear regression equation which can be written as

$$Ln(y_p - y_{arp}) = k'''_p - \frac{x_{cp}}{X''_{cp}} - \frac{x_{cc}}{X''_{cc}} - \frac{x_{cp}x_{cc}}{X_{cpcc}} \tag{42}$$

where k'''_p, X''_{cp}, X''_{cc}, and X_{cpcc} are new constants. Rearrangement of Eq. (42) yields

$$y_p = y_{arp} + k'''_p e^{-\left(\frac{x_{cp}}{X''_{cp}} + \frac{x_{cc}}{X''_{cc}} + \frac{x_{cp}x_{cc}}{X_{cpcc}}\right)} \tag{43}$$

where k'''_p is a new constant. Here, the intraspecific competition effect $\left(\frac{1}{X''_{cc}} + \frac{x_{cp}}{X_{cpcc}}\right)$ of corn to peanut depends on the competitive

peanut density (x_{cp}). Partially differentiating Eq. (43) separately with respect to x_{cp} and x_{cc} yields

$$\frac{\partial y_p}{\partial x_{cp}} = -k''''_p\left(\frac{1}{X''_{cp}} + \frac{x_{cc}}{X_{cpcc}}\right)e^{-\left(\frac{x_{cp}}{X''_{cp}} + \frac{x_{cc}}{X''_{cc}} + \frac{x_{cp}x_{cc}}{X_{cpcc}}\right)} \tag{44}$$

and

$$\frac{\partial y_p}{\partial x_{cc}} = -k''''_p\left(\frac{1}{X''_{cc}} + \frac{x_{cp}}{X_{cpcc}}\right)e^{-\left(\frac{x_{cp}}{X''_{cp}} + \frac{x_{cc}}{X''_{cc}} + \frac{x_{cp}x_{cc}}{X_{cpcc}}\right)} \tag{45}$$

From Eqs. (44) and (45), it can be said that one competitive peanut plant at density x_{cp} is equivalent to $\left(\frac{1}{X''_{cc}} + \frac{x_{cp}}{X_{cpcc}}\right)/\left(\frac{1}{X''_{pc}} + \frac{x_{cc}}{X_{ccpc}}\right)$ competitive corn plants at density x_{cc} in giving equal effect on y_p. Practically speaking, when x_{cp} by x_{cc} interaction is present, the competition coefficient of corn to peanut is corn and peanut densities dependent. Competition index of peanut to corn ($CI_{p \text{ to } c}$) was similarly calculated by using formulae which in the forms of Eqs. (38) through (45), but by redefining y_c, y_{arc}, x_{cc}, x_{cp}, X_{cc}, X_{cp}, and X_{cccp} as respective terms that referred to corn response per plant.

The above competition indices were calculated for both TDM and reproductive (peanut pod or corn ear yield) yields per plant. These could be done since TDM and reproductive yield per plant had their own respective apparent residual (y_{ar}), response at competition free (y_o), and competitive density constant (X_c) values in the response per plant vs. density relationship [as shown in Eq. (22) of Chapter II].

Environmental Differentiation Index

As discussed in Chapter II, competitive density constant (X_c) is defined as the number of plants per competitive area ($DMAX^2$) needed to reduce maximum differentiable response (TDM or reproductive yield per plant) of a particular species in a given environment to its e^{-1} = 37%. For a given species, this value is very much related to the environment, which can vary due to edaphic, biological and management factors.

From the above phenomena, it is postulated that, where both component crops use resources accordingly (adding up to 100%) from exactly the same environment (or interpreted as not differentiating the environment), the ratio in competitive density constant between the first and second crops in affecting equal response per plant of the second should be equal to the ratio in affecting the response per plant of the first. Thus, the division product between the above two ratios is unity. In the case of peanut-sweetcorn association, the above relationship can be expressed mathematically (with prime notations deleted) as

$$\frac{X^c_{cp}}{X^c_{cc}} \div \frac{X^p_{cp}}{X^p_{cc}} = 1 \qquad (46)$$

or

$$\frac{X^p_{cp}}{X^p_{cc}} \div \frac{X^c_{cp}}{X^c_{cc}} = 1$$

where X^c_{cp} = peanut competitive density constant that is adjusted to corn competitive area ($CDMAX^2$) in affecting corn response per plant,

X^c_{cc} = corn competitive density constant (plants $CDMAX^{-2}$) in affecting corn response per plant,

X^p_{cc} = corn competitive density constant that is adjusted to peanut competitive area ($PDMAX^2$) in affecting peanut response per plant,

X^p_{cp} = peanut competitive density constant (plants $PDMAX^{-2}$) in affecting peanut response per plant.

If the above function [Eq. (46)] is greater than unity, then the environment is assumed to be differentiated for each of component crops in association, or the crops are relatively in the "two different environments." Thus Eq. (46) can be used to determine the environmental differentiation index (EDI), expressed as

$$EDI = \frac{X^c_{cp}}{X^c_{cc}} \cdot \frac{X^p_{cc}}{X^p_{cp}} \tag{47}$$

Since $CI_{p \text{ to } c} = \frac{X^c_{cp}}{X^c_{cc}}$ and $CI_{c \text{ to } p} = \frac{X^p_{cc}}{X^p_{cp}}$, then Eq. (47) can be expressed as

$$EDI = CI_{p \text{ to } c} \cdot CI_{c \text{ to } p} \tag{48}$$

If EDI = 1 [Eq. (46)], then peanut and corn behave as though they are grown exactly in the same resource environment. The division of resources and other growth factors among component crops is indicated

by the values of respective CI. For example, if $CI_{p \text{ to } c} > CI_{c \text{ to } p}$, then the environmental resources are utilized more for corn than for peanut growth or yield. However if $CI_{p \text{ to } c} = CI_{c \text{ to } p}$, i.e., the value of each CI is 1:1, then the environmental resources are divided equally for both corn and peanut, and both corn and peanut are equally competitive. However, the "exact" or "near exact" equality situation is likely to happen more for component crops of about equal physical structure, physiological requirements and DMAX values, for example, a mixture of genotypes of the same crop.

If EDI < 1, it is also considered that component crops are grown in the same resource environment, but the environmental resources are insufficient for component crops, perhaps the resource environment is not conducive for such associative cropping. The dominant and suppressed crops in the association can be indicated by their CI values.

If EDI > 1, then each component crop is in relatively different resource environment or they are differentiating the environment. For example, the overstory crop is in the "high-light regime environment" while the understory is in the "low-light environment." The relative quality and suitability of each environment for each crop is again indicated by the respective CI value. Generally, the higher the EDI value, the higher is the degree of environmental differentiation for component crops in association.

If there is an interation between corn and peanut densities in affecting corn and/or peanut yield per plant, the EDI should be also

computed by Eq. (47), except the appropriate $CI_{p \text{ to } c}$ and $CI_{c \text{ to } p}$ would have to be used. As generated from Eqs. (39) and (40), $CI_{c \text{ to } p}$ is the peanut and corn densities dependent. A similar procedure is used for $CI_{p \text{ to } c}$ if interaction would have been detected.

Biological Efficiency Indices

The land equivalent ratio (LER) (IRRI, 1974; Willey, 1979a; Mead and Willey, 1980) and area-time equivalency ratio (ATER) (Hiebsch and McCollum, 1987) were computed in this study from the data of TDM and reproductive yields per hectare. In addition, the LER based yield proportions (Mead and Willey, 1980) of peanut and corn were also calculated. The above was to assess the contribution of the component crops in the resulting total LER. The LER is expressed as

$$LER = \frac{Y_p^i}{Y_p^m} + \frac{Y_c^i}{Y_c^m} \tag{49}$$

where Y_p^i and Y_p^m are peanut yields per unit area in inter- and monocropping, respectively, and Y_c^i and Y_c^m are the respective yields for corn yields. The ATER is expressed as

$$ATER = [\frac{Y_p^i t_p^m}{Y_p^m} + \frac{Y_c^i t_c^m}{Y_c^m}]/t^i \tag{50}$$

where t_p^m, t_c^m, and t^i are durations of the production cycle in peanut monoculture, corn monoculture, and inter- or relaycropping system, respectively. The LER based yield proportions of peanut and corn were

calculated as

$$\text{Peanut yield proportion} = [\frac{Y_p^i}{Y_p^m}]/\text{LER} \qquad (51)$$

and thus

$$\text{Corn yield proportion} = 1 - [\text{peanut yield proportion}] \qquad (52)$$

Equations (51) and (52) were also similarly used in obtaining the ATER based yield proportions of peanut and corn.

In estimating LER, ATER, and yield proportion, the responses (TDM and reproductive yields) of corresponding (to their counterparts in associative environments) and standard (at density normally used in the region) sole crops were used. The former could be used directly in determining biological efficiency of the system while the latter could additionally be used for comparisons among treatments.

Results and Discussion

Competition Index

Competition index generating functions for peanut and corn TDM and reproductive yields per plant are presented in Tables 14 and 15, respectively. Except for the peanut TDM per plant from N-fertilized relayplanting related relaycropping (one that also used peanut monocropping-(R) in the regression analysis) in cycle 3, all peanut x corn density interactions in affecting peanut and corn per plant responses (TDM, pod and ear yields) in all cycles were considered not significant. However, the equation (of the above exception) reported

Table 14. Equations[†] of peanut TDM or pod yield per plant (y_p) against peanut competitive density (x_{cp})[+] and corn density adjusted to PDMAX[2] (x_{cc})[++] in inter- and relaycropping systems in three cycles of experimentation on a Malaysian histosol.

Nitrogen (kg ha^{-1})	System	TDM per plant	Pod yield per plant
		Cycle 1	
150	Intercropping	$y_p = 13.87 + 81.59e^{-(\frac{x_p}{10.4} + \frac{x_c}{6.7})}$	$y_p = 4.30 + 46.08e^{-(\frac{x_p}{8.8} + \frac{x_c}{5.2})}$
150	Relaycropping[°]	$y_p = 10.04 + 79.63e^{-(\frac{x_p}{13.0} + \frac{x_c}{1.3})}$	$y_p = 4.62 + 48.83e^{-(\frac{x_p}{8.4} + \frac{x_c}{1.1})}$
150	Relaycropping[¶]	$y_p = 4.28 + 22.94e^{-(\frac{x_p}{17.1} + \frac{x_c}{51.9^n})}$	$y_p = 2.03 + 13.68e^{-(\frac{x_p}{11.7} + \frac{x_c}{28.6^n})}$
0	Intercropping	$y_p = 8.46 + 69.70e^{-(\frac{x_p}{6.1} + \frac{x_c}{4.7})}$	$y_p = 2.72 + 19.30e^{-(\frac{x_p}{10.9} + \frac{x_c}{6.5})}$
0	Relaycropping[°]	$y_p = 6.34 + 61.17e^{-(\frac{x_p}{8.6} + \frac{x_c}{1.3})}$	$y_p = 2.15 + 19.61e^{-(\frac{x_p}{14.3} + \frac{x_c}{1.3})}$
0	Relaycropping[¶]	$y_p = 3.68 + 16.54e^{-(\frac{x_p}{19.9} + \frac{x_c}{8.9})}$	$y_p = 1.19 + 8.05e^{-(\frac{x_p}{18.4} + \frac{x_c}{7.6})}$

		Cycle 2	
150	Intercropping	$y_p = 11.77 + 70.08e^{-(\frac{x_p}{15.7} + \frac{x_c}{3.6})}$	$y_p = 3.29 + 28.79e^{-(\frac{x_p}{15.0} + \frac{x_c}{5.0})}$
150	Relaycropping°	$y_p = 7.25 + 72.45e^{-(\frac{x_p}{19.5} + \frac{x_c}{1.3})}$	$y_p = 2.30 + 29.02e^{-(\frac{x_p}{18.2} + \frac{x_c}{1.3})}$
150	Relaycropping¶	$y_p = 5.31 + 40.76e^{-(\frac{x_p}{9.8} + \frac{x_c}{4.5})}$	$y_p = 1.56 + 17.46e^{-(\frac{x_p}{9.5} + \frac{x_c}{3.5})}$
0	Intercropping	$y_p = 7.17 + 46.98e^{-(\frac{x_p}{16.1} + \frac{x_c}{4.6})}$	$y_p = 2.39 + 26.33e^{-(\frac{x_p}{9.5} + \frac{x_c}{6.3})}$
0	Relaycropping°	$y_p = 4.45 + 48.85e^{-(\frac{x_p}{20.1} + \frac{x_c}{0.8})}$	$y_p = 1.33 + 27.88e^{-(\frac{x_p}{11.1} + \frac{x_c}{1.0})}$
0	Relaycropping¶	$y_p = 3.47 + 23.05e^{-(\frac{x_p}{11.2} + \frac{x_c}{3.4})}$	$y_p = 0.96 + 11.12e^{-(\frac{x_p}{9.2} + \frac{x_c}{3.3})}$
		Cycle 3	
150	Intercropping	$y_p = 8.47 + 47.89e^{-(\frac{x_p}{17.8} + \frac{x_c}{3.2})}$	$y_p = 2.25 + 20.02e^{-(\frac{x_p}{14.1} + \frac{x_c}{4.4})}$
150	Relaycropping°	$y_p = 8.88 + 48.77e^{-(\frac{x_p}{16.9} + \frac{x_c}{1.3})}$	$y_p = 3.08 + 19.87e^{-(\frac{x_p}{12.5} + \frac{x_c}{1.6})}$

Table 14--continued.

Nitrogen (kg ha^{-1})	System	TDM per plant	Pod yield per plant
150	Relaycropping[¶]	$y_p = 5.85 + 29.53e^{-(\frac{x_p}{4.9} - \frac{x_c}{24.3})}$	$y_p = 1.96 + 16.38e^{-(\frac{x_p}{7.0} + \frac{x_c}{16.1})}$
0	Intercropping	$y_p = 8.33 + 43.13e^{-(\frac{x_p}{11.5} + \frac{x_c}{1.9})}$	$y_p = 2.47 + 22.77e^{-(\frac{x_p}{8.2} + \frac{x_c}{2.6})}$
0	Relaycropping[°]	$y_p = 7.64 + 44.21e^{-(\frac{x_p}{11.7} + \frac{x_c}{1.8})}$	$y_p = 2.38 + 20.30e^{-(\frac{x_p}{8.4} + \frac{x_c}{6.7})}$
0	Relaycropping[¶]	$y_p = 4.70 + 22.62e^{-(\frac{x_p}{10.1} + \frac{x_c}{31.5^m})}$	$y_p = 1.79 + 11.42e^{-(\frac{x_p}{10.3} + \frac{x_c}{32.6})}$

† : Equations are in the form of $y_p = y_{arp} + (y_{op} - y_{arp})e^{-(\frac{x_{cp}}{X_{cp}} + \frac{x_{cc}}{X_{cc}})}$, where y_{op} and y_{arp} are peanut TDM or pod yield per plant at competition-free and its apparent residual, respectively; and X_{cp} and X_{cc} are related peanut and corn density constants, respectively. X_{op} and X_{cc} followed by letters m and n have (estimate)/(asymptotic standard error) < critical t_∞ values at $\alpha = 0.05$ and $\alpha = 0.10$ levels, respectively, and consequently respective X_{cp} and/or X_{cc} tend to be very large.

+ : x_{cp} = (peanut plants-1)$PDMAX^{-2}$, where $PDMAX^2 = 1.0\ m^2$.

++ : x_{cc} = corn plants $PDMAX^{-2}$.

° and ¶ : Monocroppings that correspond to inter- and relayplanting dates, respectively, were used as peanut TDM or yield per plant at 0 corn plants $PDMAX^{-2}$, and used as ones of the input in the analyses.

Table 15. Equations[†] of sweetcorn TDM or ear yield per plant (y_c) against corn competitive density (x_{cc})[+] and peanut density adjusted to CDMAX[2] (x_{cp})[¶] in inter- and relaycropping systems in three cycles of experimentation on a Malaysian histosol.

Nitrogen (kg ha^{-1})	Systems	TDM plant^{-1}	Ear yield plant^{-1}
		Cycle 1	
150	Intercropping	$y_c = 56.26 + 327.02e^{-(\frac{x_c}{9.0} + \frac{x_p}{152.1})}$	$y_c = 27.46 + 310.34e^{-(\frac{x_c}{13.6} + \frac{x_p}{513.1})}$
150	Relaycropping	$y_c = 52.06 + 244.65e^{-(\frac{x_c}{12.8} + \frac{x_p}{1702.7^n})}$	$y_c = 12.28 + 344.89e^{-(\frac{x_c}{17.4} - \frac{x_p}{44444.4^n})}$
0	Intercropping	$y_c = 15.42 + 190.83e^{-(\frac{x_c}{8.2} + \frac{x_p}{30.7})}$	$y_c = 8.14 + 386.09e^{-(\frac{x_c}{5.2} + \frac{x_p}{16.5})}$
0	Relaycropping	$y_c = 18.12 + 163.29e^{-(\frac{x_c}{10.4} + \frac{x_p}{479.4})}$	$y_c = 6.40 + 223.26e^{-(\frac{x_c}{7.9} + \frac{x_p}{527.8})}$
		Cycle 2	
150	Intercropping	$y_c = 51.35 + 174.36e^{-(\frac{x_c}{15.8} + \frac{x_p}{717.2})}$	$y_c = 23.54 + 195.78e^{-(\frac{x_c}{20.8} + \frac{x_p}{3249.9^n})}$

150	Relaycropping	$y_c = 52.70 + 228.92e^{-(\frac{x_c}{12.8} + \frac{x_p}{735.9})}$	$y_c = 37.93 + 240.43e^{-(\frac{x_c}{14.7} - \frac{x_p}{19342.4^n})}$
0	Intercropping	$y_c = 43.11 + 137.29e^{-(\frac{x_c}{12.4} + \frac{x_p}{37.3})}$	$y_c = 27.09 + 214.48e^{-(\frac{x_c}{11.1} + \frac{x_p}{23.2})}$
0	Relaycropping	$y_c = 34.79 + 146.83e^{-(\frac{x_c}{13.6} - \frac{x_p}{2490.0^n})}$	$y_c = 16.04 + 228.37e^{-(\frac{x_c}{10.9} - \frac{x_p}{12437.8^n})}$

- - - - - - - - - - - - - - - - - Cycle 3 - - - - - - - - - - - - - - - - -

150	Intercropping	$y_c = 43.53 + 173.38e^{-(\frac{x_c}{14.2} + \frac{x_p}{494.6})}$	$y_c = 19.09 + 268.20e^{-(\frac{x_c}{12.9} + \frac{x_p}{498.3})}$
150	Relaycropping	$y_c = 52.14 + 189.20e^{-(\frac{x_c}{12.1} - \frac{x_p}{3625.8^n})}$	$y_c = 32.22 + 369.09e^{-(\frac{x_c}{10.3} + \frac{x_p}{1971.6^n})}$
0	Intercropping	$y_c = 29.83 + 193.80e^{-(\frac{x_c}{9.5} + \frac{x_p}{22.6})}$	$y_c = 11.27 + 227.62e^{-(\frac{x_c}{10.5} + \frac{x_p}{15.5})}$
0	Relaycropping	$y_c = 23.74 + 169.30e^{-(\frac{x_c}{12.8} + \frac{x_p}{4115.2^n})}$	$y_c = 8.99 + 309.40e^{-(\frac{x_c}{9.0} + \frac{x_p}{1946.3^n})}$

Table 15--continued.

$$-\left(\frac{X_{cc}}{X_{cc}} + \frac{X_{cp}}{X_{cp}}\right)$$

†: Equations are in the form of $y_c = y_{arc} + (y_{cc} - y_{arc})e$, where y_{cc} and y_{arc} are corn TDM or ear yield per plant at competition-free at its apparent residual, respectively. The X_{cc} and X_{pc} are related corn and peanut density constants, respectively. The X_{cc} and X_{pc} followed by letter n have (estimate)/(asymptotic standard error) < critical t_∞ value at $\alpha = 0.10$ level, and consequently X_{cc} and/or X_{pc} tend to be very large.

+: x_{cc} = (corn plants-1) $CDMAX^{-2}$, where $CDMAX^2 = 3.24\ m^2$.

¶: x_{cp} = peanut plants $CDMAX^{-2}$.

in Table 14 is in the form of Eq. (39), i.e., without interaction term. The competition indices (CI) based on the TDM and reproductive yield per plant and generated from the competitive density constants shown in Tables 14 and 15 are presented in Table 16.

In all environments of all cycles, the competition index of peanut to corn ($CI_{p \text{ to } c}$) (equivalent number of peanut plants to one corn plant in giving equal effect of average TDM or ear yield per plant of corn) ratios were higher than those of corn to peanut ($CI_{c \text{ to } p}$) (equivalent number of corn plants to one peanut plant in affecting average TDM or yield per plant of peanut) (Table 16). Particularly, the above differences were much wider in the relaycropping environment. For example, in the N-fertilized plots of cycle 1, the respective $CI_{p \text{ to } c}$ ratios with respect to TDM and ear yields were 133.0:1 and 2554.2:1, respectively, while $CI_{c \text{ to } p}$ for peanut TDM and pod yields were only 0.10:1 and 0.13:1, respectively. In contrast, the differences were small for the non-N-fertilized intercropping environments. For example, in cycle 1, the $CI_{p \text{ to } c}$ values were 3.7:1 and 3.2:1 (with respect to corn TDM and ear yield, respectively), whereas $CI_{c \text{ to } p}$ were 0.77:1 and 0.60:1 (with respect to peanut TDM and pod yields, respectively). The above findings suggest that generally corn was more competitive in affecting growth of peanut than peanut was in affecting growth of corn in cropping associations in the Malaysian peat. In relaycropping, i.e., with short overlapping duration between immature relaycrop peanut and maturing corn, corn competitive effectiveness dramatically increased relative to peanut, thus corn growth and yield approached to that of

Table 16. Competition index expressed as plant equivalency in affecting TDM and reproductive yield per plant; and environmental differentiation index in inter- and relaycropping system in three cycles of experimentation on a Malaysian histosol.

Nitrogen (kg ha^{-1})	System	Competition index: Corn to peanut ($CI_{c \text{ to } p}$) DM plant^{-1}	Corn to peanut ($CI_{c \text{ to } p}$) Pod wt. plant^{-1}	Competition index: Peanut to corn ($CI_{p \text{ to } c}$) DM plant^{-1}	Peanut to corn ($CI_{p \text{ to } c}$) Ear wt. plant^{-1}	Environmental Differentiation Index (EDI): DM plant^{-1}	EDI: Yield plant^{-1}
		corn:peanut	corn:peanut	peanut:corn	peanut:corn		
				Cycle 1			
150	Intercropping	0.64†:1	0.59†:1	16.9:1	37.7:1	10.8	22.2
150	Relaycropping°	0.10:1	0.13:1	133.0:1	2554.2†:1	13.3	TL*
150	Relaycropping¶	3.03:1	2.44:1	-	-	403.0‡	TL‡
0	Intercropping	0.77:1	0.60:1	3.7:1	3.2:1	2.8	1.9
0	Relaycropping°	0.15:1	0.09:1	46.1:1	66.8:1	6.9	6.0
0	Relaycropping¶	0.45:1	0.41:1	-	-	20.7‡	27.4‡
				Cycle 2			
150	Intercropping	0.23:1	0.33:1	45.4:1	156.2:1	10.4	51.5
150	Relaycropping°	0.07:1	0.07:1	57.5:1	1315.8†:1	4.0	TL
150	Relaycropping¶	0.46:1	0.37:1	-	-	26.4‡	TL‡
0	Intercropping	0.28:1	0.66:1	3.0:1	2.1:1	0.8	1.4
0	Relaycropping°	0.04:1	0.09:1	183.1†:1	1141.1†:1	TL	TL
0	Relaycropping¶	0.30:1	0.36:1	-	-	TL‡	TL‡

				Cycle 3			
150	Intercropping	0.18:1	0.31:1	34.8:1	38.6:1	6.3	11.9
150	Relaycropping°	0.08:1	0.13:1	299.6:1	191.4:1	23.9	24.9
150	Relaycropping¶	4.96:1#	2.30:1	-	-	TL‡	440.2‡
0	Intercropping	0.16:1	0.32:1	2.4:1	1.5:1	0.4	0.5
0	Relaycropping°	0.15:1	0.80:1	321.5:1	216.3:1	48.2	173.0
0	Relaycropping¶	3.12:1	3.16:1	-	-	1003.1‡	683.5‡

†: Due to small figure, two decimal point was used.

+: Too high equivalent number of peanut plants to one corn plant in giving oppositely equal effect on corn response per plant and thus should be interpreted as not reducing the corn response. It could also be interpreted as too high plant numbers was required in reducing the counterpart corn response. This is clearly shown by Table 15 where respective X_{cc} tended to be too large, and hence $1/X_{cc} \to 0$, and consequently, at normal peanut density range, $x_{cc}/X_{cc} \to 0$.

° and ¶: Monocroppings that correspond to inter- and relayplanting dates, respectively, were used as peanut TDM or pod yield per plant at 0 corn plant $PDMAX^{-2}$, and used as ones of the inputs in the analyses in Table 14.

#: Mathematically gave equal opposite effect, and thus relaycrop peanut TDM per plant was not reduced by corn. See Table 14.

*: TL is referred as too large index value. This was due to either + or # in the above, i.e., one component crop response was not reduced by the other component crop (or needed too large plant number in reducing the other component crop response), and thus the EDI = $CI_{p \text{ to } c} \cdot CI_{c \text{ to } p}$ was also then considered too large.

‡: $CI_{p \text{ to } c}$ at relaycropping was again used in computing the EDI.

corn monoculture. However, the corn competitive effectiveness was greatly reduced when grown under non-N-fertilized intercropping environments, where peanut competitive effectiveness became relatively close to that of corn. Non-N-fertilized corn growth on peat was stunted, and thus intercrop peanut presumably received more light, and consequently produced reasonable peanut growth that probably was able to compete for edaphic growth limiting factors, especially N.

Table 16 shows that the $CI_{c \text{ to } p}$ ratio which pertained to peanut TDM in N-fertilized intercropping environment in cycle 1 was 0.64:1. In other words, one peanut plant was equivalent to 0.64 corn plants in giving equal effect on peanut TDM per plant. The respective $CI_{c \text{ to } p}$ ratios for cycles 2 and 3 were 0.23:1 and 0.18:1, respectively. These ratios were higher than those in N-fertilized interplanting related relaycropping (one that also included peanut monocropping-(I) in the regression analysis) environments in their respective cycles (0.10:1, 0.07:1, and 0.08:1 for cycles 1, 2, and 3, respectively), but lower than those in N-fertilized relayplanting related relaycropping treatments [peanut monocropping-(R) was also used in the analysis] (3.03:1, 0.46:1, and 4.96:1 for cycles 1, 2, and 3, respectively). The values of $CI_{c \text{ to } p}$ with respect to pod yield per plant were similar to the TDM per plant tendencies (Table 16). The findings suggest that under N-fertilized peat environment, individual intercrop peanut total and reproductive growth were reduced by corn. This affect was further increased in relaycrop peanut due to applied N uptake by the early-grown corn plus some N loss which resulted in very low available N at relayplanting time (as discussed

in Chapter II). With this CI equivalency concept, the actual competition experienced by peanut would increase with higher crop mixture density (especially with higher corn density). As discussed previously in Chapter II, even without corn cropping, available soil N and probably some other nutrients at previously fertilized plots were low at relayplanting time which was reflected by the reduced individual total and reproductive growth of peanut monocropping-(R). If this was taken into consideration, relaycrop peanut was much less affected by corn compared to that in intercropping, especially in cycles 1 and 3. For example, based on CI values given in Table 16, 20 peanut plants m^{-2} that relayed into N-fertilized 2.7, 5.3, and 13.3 corn plants m^{-2} were equivalent to 20.9, 21.7, and 24.4 peanut plants of monocropping-(R), respectively, in affecting peanut TDM per plant in previously N-fertilized plots of cycle 1. The respective monocrop equivalencies in affecting peanut pod yield per plant in cycle 1 were 21.1, 22.2, and 25.5 peanut plants m^{-2}. The above results indicate that the equivalent relaycrop peanut densities that affected TDM and pod yield per plant were not far from 20 plants m^{-2} for monocropping-(R). Similar calculations could also be done for the other peanut densities. The above discussion might suggest that relayplanted peanut was affected little by corn (possibly less etiolation), consequently relatively vigorous peanut plants resulted. It is therefore suggested that reapplying N and other required nutrients immediately after 80-day sweetcorn harvest probably can increase growth and yield of relaycrop peanut to levels comparable to those of peanut monocropping-(I). In the non-N-fertilized

environments, except in relayplanting related relaycropping of cycle 3, all inter- and relaycrop peanut were affected by associated corn.

Table 16 shows much narrower $CI_{p \text{ to } c}$ ratios in intercroppings than those in relaycroppings in affecting both corn TDM and ear yield per plant existed under N- and non-N-fertilized treatments. Furthermore, much lower $CI_{p \text{ to } c}$ (3.7:1, 3.0:1, and 2.4:1 for corn TDM per plant in cycles 1, 2, and 3, respectively, while 3.2:1, 2.1:1, and 1.5:1 for the ear yield per plant) were found in the non-N-fertilized intercropping plots. The findings suggest that generally corn growth and yield were reduced by peanut more in intercropping, than in relaycropping. The relative intercrop reduction was more under non-N-fertilized situation. The competition experienced by corn would be higher with higher mixture density (especially with increased peanut density). With very large number of peanut plants required, seemingly relaypeanut was weak in affecting individual corn total and reproductive growth. For example, in cycle 1, the $CI_{c \text{ to } p}$ that related to corn TDM per plant for N-fertilized relaycropping was 133.0:1, interpreted as one corn plant was equivalent to 133.0 peanut plants in affecting corn TDM per plant. Thus, 5.3 corn + 80 peanut plants m^{-2} in relaycropping was equivalent to only 5.9 monocrop corn plants m^{-2}. Practically speaking, individual corn reproductive growth was likely not reduced by relayplanted peanut in the N-fertilized plots of cycles 1 and 2 (Table 16). The above was also indicated in non-N-fertilized plots of cycle 2. Even though the average relaycrop corn ear yield at non-N-fertilized in cycle 2 was seemingly lower than

that in monocropping (3148 vs. 4005 kg ha^{-1}, respectively), the above difference at each corn density did not exceed the common LSD used (Appendix Table B-4). Furthermore, by examining the raw data, there were relatively no consistent effects of relaycrop peanut density and mono- vs. relaycropping [especially at lower corn densities (2.7 and 5.3 plants m^{-2})] in affecting corn ear yields in the above environment. Therefore, this method ($CI_{p \text{ to } c}$) reconfirmed the lack of relaycrop peanut effect on corn ear yield at non-N-fertilized plot of cycle 2.

Due to very high $CI_{p \text{ to } c}$ ratios in relaycropping which indicated little or no effect of relaycrop peanut on corn (TDM and ear yield) versus low $CI_{c \text{ to } p}$ ratios (with respect to both peanut TDM and pod yield), it is therefore revealed that relaycrop peanut total and reproductive growth were suppressed by associated corn. Since corn was not affected by relayplanted peanut while the latter was greatly affected by the former, suppression rather than competition terminology should then be used. Nevertheless, if some N and other nutrient should have been lost even without associated corn cropping (due to the tropical peat soil environment), it would be generally expected that less suppression experienced by relayplanted peanut.

In general, if $CI_{p \text{ to } c}$ and $CI_{c \text{ to } p}$ were meaningful in interspecific competitions experienced by corn and peanut, respectively, the magnitude of the experienced competition would increase with increasing mixture density (with respect to peanut and corn density, respectively). This situation would exist when there was no interaction between peanut and corn density in affecting respective TDM or reproductive yield per plant (Tables 14 and 15).

Environmental Differentiation Index

The environmental differentiation index (EDI) at various environments (nitrogen x cropping system) for all three cycles are shown in Table 16. In discussing EDI, the CI values should be considered also in order to detect the degree of "environment suitability" and/or "resources partitioning" for each component crop in association.

Under the non-N-fertilized intercropping situation, the EDI values with respect to TDM (0.4 to 2.8) and reproductive yield (0.5 to 1.9) for all cycles were close to unity (Table 16). This indicates that sweetcorn and peanut were using the same resource environment, i.e., they were not differentiating the environment. Under the non-N-fertilized condition, corn growth was stunted, and thus light was considered non-limiting to both peanut and corn. Furthermore, peanut and corn grew simultaneously during intercropping and hence both crops were temporally within the same cropping period. Thus, the crops were probably simultaneously competing only for in situ soil N and other edaphic growth limiting factors. However, the $CI_{p \text{ to } c}$ ratios were slightly higher than $CI_{c \text{ to } p}$ ratios (Table 16). This suggests that within the above same environment, sweetcorn received greater "share" in resources as compared to peanut in growth and yielding under the acidic peat tropical condition. Brown (1978) indicated that C4 plants are more efficient than C3 in using N for growth. More importantly, individual corn plants are simply larger than individual peanut plants.

By applying N to the plots of intercropping, the EDI values with respect to TDM and reproductive yields in cycle 1 were increased (more than unity) to 10.8 and 22.2, respectively. The respective values for cycle 2 were 10.4 and 51.5; for cycle 3 were and 6.3 and 11.9. The above results suggest that peanut and sweetcorn were essentially grown in two different "resource environments." The N-fertilized overstory corn had heavier canopy, thus it was in a "high-light regime environment," while the understory peanut was then in the "low-light environment." However, the $CI_{p \text{ to } c}$ ratios with respect to TDM and reproductive yields were higher than $CI_{c \text{ to } p}$ ratios (Table 16). This suggests that corn had a better environment than peanut. The quality of environment for better peanut growth and yield was thus relatively "poor."

Even without corn cropping, the N status of this peat soil was low during the peanut relaycropping period due to N loss and possibly some N fixation (high C:N ratio soil). With the above consideration, the related EDI with respect to TDM and reproductive yields for N-fertilized relaycropping in cycle 1 were 403.0 and TL (index considered too large), respectively (Table 16). The respective values for cycle 2 were 26.4 and TL; and for cycle 3 were TL and 440.2, respectively. The above EDI values were much larger (EDI >>> 1) than those of N-fertilized intercropping. These comparisons suggest that under the N-fertilized relaycropping the environmental differentiations for sweetcorn and peanut growth and yield were related to the difference in time of cropping (time-related growth factors) and associated soil-N regime. However, the difference

between $CI_{p \text{ to } c}$ and $CI_{c \text{ to } p}$ indicate that corn had better environment (related to recent liming, N and other nutrients fertilizations) than peanut. On the other hand, in the non-N-fertilized relaycropping, it is presumed that the environment differentiation was mainly due to a difference in the time-related growth factors and non-N nutrients regimes.

Biological Efficiency Indices

Monocrop TDM and reproductive yields of corn and peanut at 5.3 and 20.0 plants m^{-2}, respectively, at each N-fertilization level were used as the denominators or bases in computing land equivalent ratio (LER) and area-time equivalency ratio (ATER) of the peanut-sweetcorn inter- and relaycropping systems. The above densities were chosen due to their frequent uses in the region (Malaysian environment), and thus the system relative biological efficiencies at other densities could be compared. Mead and Willey (1980) indicated that the method of standardization should vary according to the form and objective of the experiment. Huxely and Maingu (1978) emphasized that all intercrop yields should be compared against their monoculture optimum population and spacing. In spite of having two types of monoculture peanut controls, only the monocropping-(I) response was used in computing LER and ATER of inter- and relaycropping systems in order to compare the degree of resource utilization (Willey, 1979a) between the above systems. The LER and ATER values with respect to TDM yield per ha are presented in Tables 17 and 18, whereas those related to ear and pod yields are given in Tables 19 and 20. As comparisons, the values which were calculated by using yields of corresponding monocultures

Table 17. Land equivalent ratio (LER) and area-time equivalency ratio (ATER) with respect to TDM yield per hectare based on monocrop TDM yields at standard corn and peanut densities (as frequently practiced in the area)† in the inter- and relaycropping systems in three cycles of experimentation on a Malaysian histosol.

Nitrogen	Corn density	System	LER					ATER				
			Peanut density (plants m^{-2})					Peanut density (plants m^{-2})				
(kg ha^{-1})	(plants m^{-2})	(cropping)	5	10	20	40	80	5	10	20	40	80
			Cycle 1									
0	2.7	Inter	1.15	0.84	0.94	1.24	1.53	0.99	0.75	0.88	1.18	1.48
		Relay	1.27	1.52	1.55	1.29	1.54	0.68	0.83	0.85	0.74	0.91
	5.3	Inter	1.12	1.00	1.11	1.25	1.64	0.95	0.87	1.03	1.13	1.58
		Relay	1.27	1.53	1.99	1.95	1.90	0.69	0.85	1.09	1.10	1.10
	13.3	Inter	1.37	1.02	1.38	1.37	2.11	1.15	0.88	1.23	1.25	1.95
		Relay	1.57	1.28	1.62	1.60	2.05	0.84	0.69	0.88	0.91	1.16
150	2.7	Inter	1.25	1.55	1.32	1.78	2.15	1.11	1.35	1.22	1.70	2.06
		Relay	0.98	1.01	1.21	1.06	1.16	0.53	0.56	0.67	0.60	0.67
	5.3	Inter	1.25	1.26	1.26	1.57	2.06	1.04	1.08	1.11	1.45	1.93
		Relay	1.30	1.17	1.55	1.42	1.97	0.70	0.64	0.87	0.80	1.13
	13.3	Inter	1.35	1.46	2.07	1.91	2.22	1.14	1.26	1.77	1.69	2.02
		Relay	1.44	1.70	1.42	1.65	1.83	0.78	0.92	0.79	0.92	1.03
			Cycle 2									
0	2.7	Inter	0.69	0.84	1.04	0.97	1.29	0.60	0.76	0.96	0.91	1.22
		Relay	0.77	0.70	0.78	0.95	1.19	0.41	0.38	0.43	0.53	0.69
	5.3	Inter	0.94	0.82	0.89	1.25	1.42	0.80	0.72	0.80	1.16	1.32
		Relay	0.92	0.83	1.15	1.31	1.30	0.50	0.45	0.63	0.72	0.74
	13.3	Inter	1.26	1.25	1.63	1.61	1.70	1.04	1.05	1.40	1.42	1.52
		Relay	1.15	1.18	1.36	1.39	1.49	0.61	0.63	0.73	0.76	0.83

150	2.7	Inter	0.95	1.14	1.14	1.84	1.71	0.81	1.00	1.05	1.70	1.60
		Relay	0.93	1.02	0.87	0.92	1.18	0.51	0.55	0.49	0.52	0.68
	5.3	Inter	1.24	1.25	1.42	1.59	2.16	1.04	1.07	1.24	1.42	1.98
		Relay	1.17	1.07	1.17	1.34	1.08	0.63	0.58	0.65	0.74	0.61
	13.3	Inter	1.56	1.64	1.65	2.06	2.26	1.28	1.37	1.41	1.77	2.00
		Relay	1.56	1.41	1.23	1.89	1.73	0.83	0.76	0.67	1.04	0.97
							Cycle 3					
0	2.7	Inter	0.71	0.69	1.13	1.12	2.34	0.61	0.62	1.05	1.07	2.27
		Relay	1.05	1.25	1.36	1.57	1.83	0.58	0.70	0.78	0.91	1.09
	5.3	Inter	0.73	1.23	0.96	1.18	1.91	0.64	1.07	0.88	1.09	1.81
		Relay	1.26	1.48	1.29	1.79	2.16	0.68	0.81	0.73	1.03	1.28
	13.3	Inter	1.03	1.32	1.37	1.54	2.40	0.87	1.12	1.21	1.40	2.22
		Relay	1.19	1.50	1.63	1.62	2.13	0.67	0.83	0.91	0.92	1.27
150	2.7	Inter	0.91	1.05	1.17	1.59	2.20	0.78	0.92	1.05	1.47	2.10
		Relay	0.98	0.99	0.87	1.14	1.34	0.53	0.55	0.49	0.65	0.78
	5.3	Inter	1.08	1.18	1.34	1.56	1.95	0.91	1.01	1.16	1.38	1.80
		Relay	1.13	1.14	1.09	1.45	1.55	0.61	0.62	0.61	0.81	0.86
	13.3	Inter	1.35	1.49	1.35	1.73	2.39	1.10	1.25	1.14	1.47	2.16
		Relay	1.78	1.59	1.55	1.74	2.48	0.97	0.86	0.85	0.97	1.41

†: Standard monocrop peanut and corn densities were 20 and 5.3 plants m^{-2}, respectively.

Table 18. Average° land equivalent ratio (LER) and area-time equivalency ratio (ATER) with respect to TDM yield per hectare based on monocrop TDM yields at standard corn and peanut densities (as frequently practiced in the area)†; and their respective relative yield proportions in the inter- and relaycropping systems in three cycles of experimentation on a Malaysian histosol.

Nitrogen (kg ha^{-1})	Corn density (plants m^{-2})	System (cropping)	LER°			ATER°		
			LER	Peanut proportion	Corn proportion	ATER	Peanut proportion	Corn proportion
					Cycle 1			
0	2.7	Inter	1.14	0.61	0.39	1.06	0.65	0.35
		Relay	1.43	0.27	0.73	0.80	0.31	0.69
	5.3	Inter	1.22	0.53	0.47	1.11	0.57	0.43
		Relay	1.73	0.27	0.73	0.96	0.31	0.69
	13.3	Inter	1.45	0.43	0.57	1.29	0.47	0.53
		Relay	1.63	0.21	0.79	0.89	0.24	0.76
150	2.7	Inter	1.61	0.59	0.41	1.49	0.64	0.36
		Relay	1.08	0.26	0.74	0.61	0.30	0.70
	5.3	Inter	1.48	0.44	0.56	1.32	0.49	0.51
		Relay	1.48	0.27	0.73	0.83	0.31	0.69
	13.3	Inter	1.80	0.36	0.64	1.57	0.41	0.59
		Relay	1.61	0.23	0.77	0.89	0.27	0.73
					Cycle 2			
0	2.7	Inter	0.97	0.58	0.42	0.89	0.63	0.37
		Relay	0.88	0.23	0.77	0.49	0.27	0.73
	5.3	Inter	1.07	0.48	0.52	0.96	0.53	0.47
		Relay	1.10	0.22	0.78	0.61	0.26	0.74
	13.3	Inter	1.49	0.31	0.69	1.28	0.35	0.65
		Relay	1.31	0.14	0.86	0.71	0.17	0.83

150	2.7	Inter	1.36	0.52	0.48	1.23	0.57	0.43
		Relay	0.98	0.28	0.72	0.55	0.32	0.68
	5.3	Inter	1.53	0.38	0.62	1.35	0.43	0.57
		Relay	1.16	0.20	0.80	0.64	0.24	0.76
	13.3	Inter	1.84	0.26	0.74	1.57	0.30	0.70
		Relay	1.56	0.17	0.83	0.85	0.20	0.80
						Cycle 3		
0	2.7	Inter	1.20	0.62	0.38	1.13	0.66	0.34
		Relay	1.41	0.38	0.62	0.81	0.43	0.57
	5.3	Inter	1.21	0.52	0.48	1.10	0.57	0.43
		Relay	1.60	0.32	0.68	0.91	0.37	0.63
	13.3	Inter	1.53	0.41	0.59	1.36	0.46	0.54
		Relay	1.62	0.33	0.67	0.92	0.38	0.62
150	2.7	Inter	1.38	0.51	0.49	1.26	0.56	0.44
		Relay	1.06	0.31	0.69	0.60	0.36	0.64
	5.3	Inter	1.42	0.36	0.64	1.25	0.41	0.59
		Relay	1.27	0.23	0.77	0.70	0.27	0.73
	13.3	Inter	1.66	0.25	0.75	1.43	0.29	0.71
		Relay	1.83	0.24	0.76	1.01	0.28	0.72

†: Standard monocrop peanut and corn densities were 20 and 5.3 plants m^{-2}, respectively.

°: Average over five peanut densities (5, 10, 20, 40, and 80 plants m^{-2}).

Table 19. Land equivalent ratio (LER) and area-time equivalency ratio (ATER) with respect to reproductive yield per hectare based on monocrop yields at standard corn and peanut densities (as frequently practiced in the area)† in the inter- and relaycropping systems in three cycles of experimentation on a Malaysian histosol.

Nitrogen	Corn density	System	LER					ATER				
			Peanut density (plants m^{-2})					Peanut density (plants m^{-2})				
(kg ha^{-1})	(plants m^{-2})	(cropping)	5	10	20	40	80	5	10	20	40	80
			Cycle 1									
0	2.7	Inter	1.23	0.58	0.87	1.04	1.32	1.05	0.54	0.79	0.97	1.26
		Relay	1.87	1.75	2.18	1.51	1.46	0.99	0.95	1.17	0.82	0.81
	5.3	Inter	0.83	0.76	0.79	0.92	1.33	0.72	0.67	0.75	0.84	1.28
		Relay	1.28	1.73	2.07	1.78	1.81	0.69	0.94	1.15	0.99	1.01
	13.3	Inter	0.79	0.89	1.19	0.83	1.35	0.69	0.78	1.07	0.79	1.27
		Relay	1.06	0.77	0.94	0.78	1.13	0.57	0.42	0.52	0.45	0.65
150	2.7	Inter	0.92	1.39	1.23	1.26	1.84	0.81	1.23	1.12	1.18	1.73
		Relay	0.89	1.12	1.12	1.11	1.27	0.48	0.63	0.61	0.62	0.73
	5.3	Inter	1.31	1.03	1.09	1.43	1.46	1.13	0.89	0.96	1.34	1.32
		Relay	1.25	1.26	1.47	1.49	1.93	0.67	0.71	0.82	0.85	1.12
	13.3	Inter	0.80	0.83	1.23	1.23	1.44	0.68	0.72	1.07	1.11	1.31
		Relay	0.89	1.19	1.26	1.28	1.42	0.49	0.67	0.72	0.74	0.85
			Cycle 2									
0	2.7	Inter	0.89	0.81	1.18	1.08	1.57	0.79	0.76	1.11	1.01	1.51
		Relay	0.93	0.78	0.94	0.92	1.20	0.50	0.42	0.52	0.51	0.68
	5.3	Inter	1.04	0.87	0.81	1.31	1.32	0.93	0.82	0.74	1.22	1.27
		Relay	0.90	1.00	0.97	1.23	1.14	0.49	0.56	0.55	0.69	0.66
	13.3	Inter	0.97	0.64	0.85	1.38	1.73	0.83	0.60	0.78	1.29	1.65
		Relay	0.73	0.67	0.73	0.73	0.74	0.39	0.36	0.40	0.41	0.42

150	2.7	Inter	0.93	1.14	1.16	1.52	1.68	0.80	1.00	1.08	1.38	1.57
		Relay	0.86	0.91	0.85	0.94	1.21	0.46	0.49	0.47	0.52	0.68
	5.3	Inter	1.12	1.24	1.19	1.51	1.52	0.96	1.06	1.03	1.33	1.33
		Relay	1.14	1.12	1.11	1.26	0.92	0.61	0.60	0.60	0.68	0.51
	13.3	Inter	1.17	1.05	1.15	1.44	1.63	0.96	0.88	0.99	1.22	1.42
		Relay	1.18	1.17	1.14	1.46	1.02	0.63	0.63	0.62	0.80	0.56
			- - - - - - - - - - - - - - - - Cycle 3 - - - - - - - - - - - - - - - -									
0	2.7	Inter	0.74	0.84	1.26	1.36	2.21	0.66	0.80	1.20	1.32	2.18
		Relay	1.55	2.03	1.99	2.25	2.52	0.86	1.17	1.17	1.33	1.52
	5.3	Inter	0.65	0.82	0.85	1.00	1.43	0.59	0.78	0.82	0.98	1.40
		Relay	1.33	1.67	1.31	2.09	2.58	0.75	0.95	0.77	1.25	1.57
	13.3	Inter	0.54	0.63	0.77	1.06	1.67	0.49	0.58	0.73	1.04	1.62
		Relay	0.84	1.05	1.42	1.21	1.56	0.51	0.61	0.85	0.74	0.97
150	2.7	Inter	1.00	1.13	1.08	1.45	1.85	0.86	0.99	0.97	1.34	1.73
		Relay	1.12	1.29	1.15	1.52	1.41	0.60	0.71	0.65	0.86	0.82
	5.3	Inter	0.97	1.17	1.16	1.06	1.64	0.82	1.00	1.00	0.94	1.51
		Relay	1.04	1.29	1.18	1.52	1.54	0.57	0.70	0.65	0.86	0.87
	13.3	Inter	0.73	0.79	0.78	0.96	1.43	0.60	0.67	0.68	0.85	1.31
		Relay	1.11	1.10	1.15	1.32	1.60	0.62	0.61	0.64	0.75	0.92

†: Standard monocrop peanut and corn densities were 20 and 5.3 plants m^{-2}, respectively.

Table 20. Average° land equivalent ratio (LER) and area-time equivalency ratio (ATER) with respect to reproductive yield per hectare based on monocrop yields at standard corn and peanut densities (as frequency practiced in the area)†; and their respective yield proportions in the inter- and relaycropping systems in three cycles of experimentation on a Malaysian histosol.

Nitrogen (kg ha^{-1})	Corn density (plants m^{-2})	System (cropping)	LER°	LER° Peanut proportion	LER° Corn proportion	ATER°	ATER° Peanut proportion	ATER° Corn proportion
					Cycle 1			
0	2.7	Inter	1.01	0.56	0.44	0.92	0.61	0.39
		Relay	1.76	0.13	0.87	0.95	0.16	0.84
	5.3	Inter	0.92	0.57	0.43	0.85	0.61	0.39
		Relay	1.74	0.21	0.79	0.96	0.25	0.75
	13.3	Inter	1.01	0.52	0.48	0.92	0.57	0.43
		Relay	0.94	0.26	0.74	0.52	0.31	0.69
150	2.7	Inter	1.33	0.56	0.44	1.22	0.61	0.39
		Relay	1.10	0.26	0.74	0.61	0.30	0.70
	5.3	Inter	1.26	0.45	0.55	1.13	0.50	0.50
		Relay	1.48	0.30	0.70	0.83	0.35	0.65
	13.3	Inter	1.11	0.40	0.60	0.98	0.45	0.55
		Relay	1.21	0.38	0.62	0.69	0.43	0.57
					Cycle 2			
0	2.7	Inter	1.11	0.67	0.33	1.04	0.72	0.28
		Relay	0.96	0.21	0.79	0.53	0.25	0.75
	5.3	Inter	1.07	0.64	0.36	1.00	0.69	0.31
		Relay	1.05	0.28	0.72	0.59	0.32	0.68
	13.3	Inter	1.12	0.59	0.41	1.03	0.64	0.36
		Relay	0.72	0.22	0.78	0.40	0.26	0.74

150	2.7	Inter	1.28	0.50	0.50	1.17	0.55	0.45
		Relay	0.95	0.22	0.78	0.53	0.26	0.82
	5.3	Inter	1.31	0.33	0.67	1.14	0.38	0.62
		Relay	1.11	0.16	0.84	0.60	0.19	0.82
	13.3	Inter	1.29	0.25	0.75	1.10	0.29	0.71
		Relay	1.20	0.14	0.86	0.65	0.17	0.83
			- - - - - - - - - - - - - - - - - - Cycle 3 - - - - - - - - - - - - - - - - - -					
0	2.7	Inter	1.28	0.76	0.24	1.23	0.79	0.21
		Relay	2.07	0.46	0.54	1.21	0.51	0.49
	5.3	Inter	0.95	0.77	0.23	0.91	0.81	0.19
		Relay	1.80	0.48	0.52	1.06	0.54	0.46
	13.3	Inter	0.94	0.72	0.28	0.84	0.76	0.24
		Relay	1.21	0.63	0.37	0.74	0.68	0.32
150	2.7	Inter	1.30	0.50	0.50	1.18	0.55	0.45
		Relay	1.29	0.29	0.71	0.73	0.33	0.67
	5.3	Inter	1.20	0.37	0.63	1.05	0.42	0.58
		Relay	1.32	0.26	0.74	0.73	0.31	0.69
	13.3	Inter	0.94	0.35	0.65	0.82	0.40	0.60
		Relay	1.26	0.30	0.70	0.71	0.35	0.65

†: Standard monocrop peanut and corn densities were 20 and 5.3 plants m^{-2}, respectively.

°: Average over five peanut densities (5, 10, 20, 40, and 80 plants m^{-2}).

(at various monoculture densities and N levels) are presented in Appendix Tables B-5 through B-8. These provide direct measures of biological efficiencies for respective planting density x cropping system x N level treatment combinations, but are not always suitable for comparing among above treatments (Mead and Willey, 1980).

The LER (for inter- and relaycropping) and ATER (for intercropping) with respect to TDM per ha were generally > 1 (except at some lower peanut densities, especially in the non-N-fertilized plots of cycle 2) and increased with increasing corn and peanut densities (Tables 17 and 18). These findings suggest that resource exploitation for total growth were more efficient with inter- and relaycropping systems compared to the standard peanut or corn monocropping on the Malaysian peat environment. Higher mixture densities further increased efficiencies. However, relaycropping was generally much less efficient than monocropping, i.e., when time was considered (generally ATER < 1) (Tables 17 and 18). In spite of the above trends, most efficiency measurements of cropping systems have been made with respect to reproductive yields. Thus, only LER and ATER based on reproductive yields will be presented in the following discussion.

Several researchers reported higher LER and ATER in yield of intercropping or crops in association when grown without N fertilization compared to those with N fertilization (Rao and Willey, 1980; Searle et al., 1981; Ahmed and Rao, 1982; Hiebsch and McCollum, 1987). From studies conducted in 14 locations of seven countries (Australia, China, India, Philippines, Sri Lanka, Thailand, and

U.S.A.), Ahmed and Rao (1982) reported that mean LER values for maize-soybean intercropping with and without nitrogen fertilization were 1.62 and 1.40, respectively. The above trends probably suggest that under low N, associated legumes are able to use atmospheric N via nodulation giving reasonably higher yields, while nonlegumes (corn and sorghum) produce yields comparable to respective non-N sole crops (Hiebsch and McCollum, 1987). The larger LER or ATER values with lower N levels were not consistently observed on the high acidic and C:N ratio peat. Table 19 indicates that LER ranges in peanut-corn association with and without nitrogen fertilization in cycle 1 were 0.80 to 1.93 and 0.58 to 2.18, respectively. Furthermore, the respective values for cycles 2 were 0.85 to 1.68 and 0.64 to 1.73; and for cycle 3 were 0.73 to 1.64 and 0.54 to 2.58. Peanut nodulation on Malaysian peat is low even with high liming (Shamshuddin, 1983) which is probably mainly due to high acidity (Keyser and Munns, 1979). Thus, peanut yield was not high and hence the calculated LER and ATER for non-N-fertilized peanut-corn associations were not necessarily higher than those for N-fertilized cropping systems.

Even though some LER values of non-N-fertilized plots were high (Table 19), but as previously shown, the absolute yields of both corn and peanut were low, especially in the monocropping-(I). This suggests that the production of corn and peanut on the unfertilized tropical peat is uneconomic. Furthermore, both corn and peanut yields were increased with the N-fertilization (Figures 14 to 19 of Chapter II). Therefore, only LER and ATER values of N-treated plots will be presented in the following discussion. Consequently, the LER and ATER

of peanut-corn inter- and relaycropping under the tropical peat environments should then be more practical and meaningful compared to those of non-N-fertilized plots for this study.

Tables 19 and 20 generally show that LER values for all corn density x peanut density x cropping systems treatment combinations with N fertilization were generally > 1 in all cycles. Based on these three cycles of experimentation (1985 to 1986), it is suggested that when time was not considered in the production system, inter- and relayplanted peanut with corn utilized resources for reproductive growth more efficiently than either peanut (20 plants m^{-2}) and corn (5.3 plants m^{-2}) monocultures. However, when time (i.e., area-time basis) was taken into consideration, relaycropping treatments had ATER values of < 1 in all cycles (except at 5.3 corn + 80 peanut plants m^{-2} of cycle 1) (Tables 19 and 20). Manson et al. (1986) reported lower ATER (0.92 to 1.13) than LER (1.38 to 1.56) values of intercropped peanut or cowpea in cassava. Table 19 further shows that ATER values of intercropping treatments were still generally > 1 or close to 1. In the few cases (8 out of 45 cases) where the ATER were considerably < 1, they were similar to their counterpart LER values. All of the above results were attributed to two factors, viz., (a) time factor, and (b) the low peanut yields in relaycropping environments (Figures 14 to 16 of Chapter II). With 80-day sweetcorn and 100-day peanut, relaycropping had 153 days of cropping duration (peanut was relayplanted at 53 days after corn planting), while intercropping had only 100 days. When time was considered, relaycropping generally was

not more efficient biologically than either standard monocrops. In the one case where it was still more efficient, its efficiency was much lower than when time was not considered. On the other hand, intercropping was still biologically superior to relaycropping, since its unused area-time was much smaller (20 ha-days) than that in relaycropping, i.e., about (53 + 73) ha-days.

In this study, corn was considered as a base crop and peanut as an introduced crop which would increase resource exploitation by the system. With this emphasis in mind, the general trends of relationships among LER, ATER and component crop contributions in base crop (corn) density x cropping systems environments under N-fertilized peat situation will only be discussed based on the average values over five introduced crop (peanut) densities.

Table 20 shows that in cycle 1, relaycropping at about optimum corn density (5.3 plants m^{-2}) showed the highest biological efficiency (LER = 1.48) among the production systems (corn density x cropping system) employed. This situation was due to 70% LER based corn contribution where corn ear yield (7922 kg ha^{-1}, i.e., averaged over five peanut densities) resembled to that of its sole crop (7785 kg ha^{-1} at 5.3 plants m^{-2}). On the other hand, 30% peanut contribution was obtained from low relaycrop peanut yield (average of 1044 kg ha^{-1}) compared to that of its sole crop (2245 kg ha^{-1} at 20 plants m^{-2}). Furthermore, the second most efficient production system in cycle 1 was the intercropping at 2.7 corn plants m^{-2} (LER = 1.33) in which peanut contributed 56% vs. 44% from corn. Intercrop peanut grown at

low corn density gave comparable yield (on average, 1719 kg ha^{-1}) to that of its standard sole crop (2245 kg ha^{-1}). When time factor was included in determining the efficiency of the system, the superiority of relaycropping at 5.3 corn plants m^{-2} no longer held (ATER = 0.83). It was only equivalent to 127.0 ha-days (0.83 x 153 ha-days of relaycropping) of either monocrop. It was then biologically equivalent to 1.59 ha of sole 80-day sweetcorn or 1.27 ha of sole 100-day peanut, whereas the equivalent hecterage at ATER = 1.0 should be at 1.91 or 1.53 ha of sweetcorn or peanut monoculture, respectively. These considerations indicate that in order for the system to be highly biologically efficient compared to respective standard monocropping, one of the component crops should be approaching (minimally affected by second crop) its monoculture yield, or both crops should be reasonably productive. When time is critically important, for example when labor is expensive or not available, relaycropping may not be a viable option. The LER values of intercropping plots at other N-fertilized corn densities (at 5.3 and 13.3 plants m^{-2}) in cycle 1 were greater than the comparable ATER values (Table 20).

The reasons for differentials and relationships among LER, ATER, and yield proportions in cycles 2 and 3 are similar to those discussed for cycle 1 (Table 20). Basically, peanut contribution in LER or ATER was substantial or equally comparable to corn contribution under the intercropping of low corn density (2.7 plants m^{-2}) situation. On the other hand, corn was of the major importance for higher LER or ATER in

relaycropping at low corn density and in associations (both inter- and relaycropping) involving higher corn densities (5.3 and 13.3 plants m^{-2}).

As shown in Chapter II (Figures 17, 18, and 19), corn ear yields in relaycroppings were about the same as those in monocroppings in all three cycles under the N-fertilized environments. Their optimum yields were at about or near 5.3 corn plants m^{-2}. Careful examination of peanut and corn proportions that contributed to LER (Table 20) indicates that corn yields were the dominant factors (70, 84, and 74% in cycles 1, 2, and 3, respectively) in determining LER values in relaycroppings at 5.3 corn plants m^{-2}. Accordingly, as suggested in the previous discussion (also as in Chapter II), the reapplication of N (probably also some other nutrients) immediately after sweetcorn harvest might increase growth and yield of relaycrop peanut. Assuming the yield could increase to 75 to 100% of that in monocropping, then LER and ATER of the relaycropping system should also be increased. For example, initially with a LER value of 1.48 and peanut and corn proportions of 30 and 70%, respectively (Table 20), the LER value of relaycropping at 5.3 corn plants m^{-2} in cycle 1 could be increased to 1.79 to 2.04, i.e., (0.75 to 1) + 0.70 x 1.48. Furthermore, with initial ATER value of 0.83 and related peanut and corn proportions of 36 and 65%, respectively, the possible new ATER values would be 1.03 to 1.19, i.e., (0.75 to 1) x 100/153 + 0.65 x 0.83, where 100/153 was the ratio between monoculture peanut and relaycropping durations. With similar methods of calculations, the possible new LER values of

relaycropping at 5.3 corn plants m^{-2} in cycles 2 and 3 were 1.68 to 1.93 and 1.73 to 1.98, respectively. These were higher than their initial LER values (1.11 and 1.32 for cycles 2 and 3, respectively). The possible new ATER values for cycles 2 and 3 were 0.98 to 1.15 and 0.99 to 1.16, respectively, and better than their initial values (0.60 and 0.73). The above findings and assumptions suggest that with a little extra input (fertilizers, especially N), the productivity and efficiency (LER) of relaycropping at optimum corn density could become relatively higher. Even when efficiency was measured against time, a little extra fertilizer appeared to make relaycropping on peat better than or comparable to either respective monocropping. Furthermore, relaycropping (multiple cropping) could reduce the possibility of total crop loss due to unpredictable production hazards (Ahmed and Rao, 1982).

CHAPTER IV
SUMMARY AND CONCLUSIONS

The general objective of this study was to develop an alternative plant response vs. density model to those presented previously (1919 to 1984). The model is considered to have parameters that are more easily interpreted biologically. This alternative model was then applied to crops under the mono-, inter-, and relaycropping environments. It was also used as the basis in developing competition and environmental differentiation indices among component crops in associations. All model calculations herein were based on the experiments conducted in a Malaysian tropical environment on histosol (oligotrophic type) soil. Specifically, the objectives of the study were (a) to determine the effects of nitrogen (N) fertilization, cropping system (CS), and plant density on the total dry matter (TDM) and reproductive yields of sweetcorn and peanut on both a per plant and a per unit land area bases; (b) to develop a plant response vs. density model of peanut and sweetcorn under cropping system x N fertilization treatments; and (c) to determine the competition, environmental differentiation and biological efficiency indices of peanut and sweetcorn inter- and relaycropping systems as influenced by N fertilization and plant density. The experiment was repeated for three cycles (overlapping seasons) during 1985 and 1986. Due to some degree of certain treatment x cycle interactions, and more importantly

for verifying the consistenacy of the proposed plant response vs. density model, the data were analyzed separately for each cycle of experimentation.

Nitrogen fertilization (150 kg ha^{-1}) was found to be important in growing sweetcorn and peanut in this soil. High carbon:nitrogen (C:N) ratio (19.8 to 24.8) and high acidity (pH 3.5 to 3.7) were probable important reasons for the necessity in N fertilization. Among all cycles, N fertilization caused 21 to 74%, and 12 to 72% increases in peanut TDM per plant and pod yields per plant, respectively. The increases in corn TDM per plant and ear yields per plant due to N were 59 to 182%, and 58 to 199%, respectively. The increases in peanut TDM per ha and pod yields per ha due to N were 19 to 72%, and 11 to 68%, respectively, whereas the respective increases in corn TDM per ha and ear yields per ha were 58 to 199%, and 121 to 425%. Highest C:N of the soil (cycle 1) caused highest increases due to N in TDM and reproductive yields on both a per plant basis and a per ha basis in both corn and peanut. Specifically, the differences in peanut TDM or pod yields (both per plant and per ha) between N- and non-N-fertilized plots were generally larger in the mono- and inter- than in relaycropping.

The peanut per plant and per ha TDM and pod yields were greatly reduced by corn in intercropping under both N- and non-N-fertilized conditions. The reductions were further increased in the relaycropping situations. The average peanut pod yield per ha reductions by corn in inter- and relaycropping of N-fertilized plots in cycle 1 were 49 and 65%, respectively (cycle 2: 57 and 83%, cycle

3: 47 and 61%). The average pod reductions under non-N-fertilized conditions in the inter- and relaycropping for cycle 1 were 35 and 66%, respectively; for cycle 2 were 38 and 81%; and for cycle 3 were 44 and 40%. Reduction in peanut pod yields in N-fertilized intercropping was most probably due to limiting light and competition with corn for nutrients. The latter cause was probably the main reason for the yield reductions in the non-N-fertilized intercropping and especially in the N- and non-N-fertilized relaycropping treatments. Apparently the presence of corn rather than its density was more important in reducing peanut TDM and pod yields in the non-N-fertilized intercropping, and in the relaycropping plots regardless of N treatments.

The sweetcorn per plant and per ha TDM and ear yields were generally reduced by the presence of the intercrop peanut. The relative reduction was more under the non-N-fertilized plots. There were generally no differences in sweetcorn per plant and per ha TDM and ear yields between mono- and relaycropping, regardless of N treatments. The average ear yield per ha reductions by intercrop peanut for N-fertilized plots having C:N values of 24.8, 19.8, and 21.5 (cycles 1, 2, and 3, respectively) were 26, 11, and 33%, respectively. The respective reductions for the non-N-fertilized plots were 64, 56, and 74%. Stunted corn plants on the non-N-fertilized plot had possibly caused more light to be received by the understory peanut, and thus resulted in relatively better peanut growth which in turn was more competitive with corn for the edaphic growth limiting factors. Increasing peanut densities (5 to 80 plants

m^{-2}) seemed important only in the N-fertilized intercropping of cycle 1 (high C:N) and in the non-N-fertilized intercropping system of all cycles.

Analyses of variance indicated that corn and peanut TDM and reproductive yields per plant and per ha were greatly affected by their respective densities. Specifically for sweetcorn, the effect was greater on the per plant than per ha basis. The primary purpose in this regard was to examine the plant response vs. density relationship with respect to TDM and reproductive yields of each component crop under each of the cropping system x nitrogen environments. Thus the plant response vs. density equations for peanut and sweetcorn at each associative cropping (inter- or relaycropping) represented over all three sweetcorn (2.7, 5.3, 13.3 plants m^{-2}) and all five peanut (5, 10, 20, 40, and 80 plants m^{-2}) densities, respectively.

Based on the dynamics of individual plants with respect to plant density in a given competitive environment, or the proposed per plant relationship [$dy/dx_c = -K(y - y_{ar})$ for $x_c \geq 0$, where y, y_{ar}, x_c and K are yield per plant, apparent yield residual per plant, competitive plant density, and the competitive plant density related constant, respectively], the plant response vs. density relationship could be equivalently presented in either a per plant (y) or per unit area (Y) basis. The per plant related mathematical model is expressed as

$$y = \begin{cases} y_o & ; \ 0 < x \leq 1 \\ y_{ar} + (y_o - y_{ar})e^{-(x-1)/X_c} & ; \ x \geq 1. \end{cases}$$

The per unit area expression is then written as

$$Y = \begin{cases} y_o x C & ; \ 0 < x \leq 1 \\ [y_{ar} x + (y_o - y_{ar})xe^{-(x-1)/X_c}]C & ; \ x \geq 1 \end{cases}$$

In both expressions, x is plant density in plants per $DMAX^2$ (competitive area), where the competitive density is $x_c = (x - 1)$ plants $DMAX^{-2}$, while y_o, X_c, and C are the intraspecific competition free yield per plant, the competitive plant density constant (X^{-1}), and the conversion factor (yield per $DMAX^2$ to yield per specified unit area), respectively. The experimental per plant and per ha data in N x cropping system environments of all three cycles for peanut and sweetcorn were explained well by the above proposed biologically based models. For the per plant model equation, the response shapes were essentially similar in all N x CS environments for each crop in each cycle, i.e., the yield per plant decreased exponentially to a residual level (y_{ar}) with increasing density. However on a per unit area basis, the curves could show either "parabolic," "asymptotic," or "an increasing trend" relationship, depending on the y_o, y_{ar}, and X_c value, and the range of values of plant density (x). Thus, it is concluded that the dynamics of individual plants in a given

environment are important and directly related to the collective performance of all plants in that environment. The extrapolation of the curve beyond the highest experimental density used in this study should be done with caution since the models were developed for surviving plant density, thus not seeding rate or density at sowing or emergence.

Specifically, the apparent undifferentiable residuals (y_{ar}) of peanut with respect to TDM and pod yields per plant were generally positively related to the environment, i.e., highest at N-fertilized monocropping (best environment) and generally lowest at non-N-fertilized relaycropping (poorest in nutrient availability for peanut growth). We may logically assume that y_{ar} would also be affected by cultivar, planting pattern, and other management strategies. The potential peanut yield of intraspecific competition-free plants (y_o) with respect to TDM and pod yields were lowered by sweetcorn in the inter- and relaycropping systems, and also partly by the reduced soil N. The peanut competitive density constant (X_c) is defined as the required competitive peanut plants per $PDMAX^2$ (competitive peanut area and estimated as $PDMAX^2 = 1\ m^2$) to reduce the differentiable portion per plant to its $e^{-1} = 37\%$. The X_c ranges with respect to TDM per plant in cycles 1, 2, and 3 were 11.5 to 25.7, 14.1 to 24.9, and 7.5 to 14.6 plants $PDMAX^{-2}$, respectively. The X_c ranges of plants per $PDMAX^2$ with respect to pod yield per plant were 8.9 to 27.1, 11.5 to 18.6, and 7.5 to 22.6 plants $PDMAX^{-2}$, i.e., about the same as for TDM yield.

In corn, the apparent residual (y_{ar}) (with respect to TDM and ear yields) was generally increased with N fertilization. Potential TDM and ear yields (y_o) were reduced somewhat by intercrop peanut and were increased by N fertilization. The corn competitive density constant (X_c) with respect to corn ear yield in cycles 1,2, and 3 were 5.5 to 17.8, 10.3 to 27.5, and 6.2 to 14.4 plants $CDMAX^{-2}$ ($CDMAX^2 = 3.24\ m^2$), i.e., about the same as for TDM yield. The X_c values with respect to ear yield of non-N-fertilized plots were generally lower than those of the N-fertilized, suggesting that N for ear production was exhausted earlier in the non-N than in the N plots.

Based on the previously mentioned models, the TDM yield per ha vs. density relationships of peanut and sweetcorn in mono-, inter-, or relaycropping at two N levels were either asymptotic, near asymptotic, or increasing trend. Asymptotic or near asymptotic trends were more frequently found on the non-N-fertilized than on the N-fertilized plots of the tropical peat soil. In the increasing trend situations, the apparent residual (y_{ar}) became important relative to potential TDM yield (y_o) in the high-density regions, as was reflected in the relatively low differentiable portion ratios [$(y_o - y_{ar}):y_{ar}$]. The rate of increase would be higher at high density, if the above trend was coupled with a higher plant dynamic (lower X_c). In effect, the first term of Eq. (33) became dominant in the mid to high density range. The Malaysian tropical oligotrophic peat which is characterized by high C:N ratio, acidity and CEC was probably providing an environment of increasing trend response in peanut or corn TDM per ha vs. density relationship. It might be related to

situations where at higher densities, the presence of plants is more effective than size of individual plants in the uptake of nutrients.

The peanut pod yield per ha vs. density relationship curves were either asymptotic, near asymptotic, or increasing trend. The increasing trend was prominent under N-fertilized monocropping environment of all cycles. The ear yield vs. density relationships in all N x cropping system environments of all three cycles were generally parabolic. Low y_{ar} values relative to y_o, i.e., as indicated by wide differentiable portion ratio $[(y_o - y_{ar}):y_{ar}]$, explained the parabolic response. Lower X_o caused lower corn ear yield optimum density in the non-N-fertilized plots compared to those in the N-fertilized plots. The optimum corn densities in the N-fertilized monocropping plots that were previously left fallow (cycle 1), grown to corn (cycle 2), and grown to cassava (cycle 3) were 19.7, 30.7, and 14.5 plants $CDMAX^{-2}$, respectively (6.1, 9.5, and 4.5 plants m^{-2}). The optimum densities in the N-fertilized intercropping crops in cycles 1, 2, and 3 were 18.4, 32.6, and 17.7 plants $CDMAX^{-2}$, respectively (5.7, 10.1, and 5.5 plants m^{-2}), whereas the respective densities in the N-fertilized relaycropping were 19.3, 27.9, and 13.6 plants $CDMAX^{-2}$ (5.9, 8.6, and 4.2 plants m^{-2}, respectively). The indicated optimum densities in cycle 2 for mono-, inter-, and relaycropping were not far from those in cycle 1 with respect to ear yields of cycle 2. It can be concluded that the optimum corn density among three cycles in mono-, inter-, and relaycropping were close to the normally used density (5.3 plants m^{-2}) in the region.

From peanut pod yield per ha vs. density relationships, the highest monocropping yields on the N-fertilized plots were at 80 plants m^{-2}. In the N-fertilized intercropping plots, pod yields (over three corn densities) at 80 peanut plants m^{-2} were generally not much higher than those at 20 to 40 plants m^{-2}. In the N-fertilized relaycropping plots, the beginnings or onsets of asymptotic and near asymptotic phases in plots that were previoulsy cropped to corn and cassava, respectively, were at 20 peanut plants m^{-2}. Due to the predicted yield improvement of relaycrop peanut if refertilized (also N) immediately after the corn harvest, a density of 80 peanut plants m^{-2} should be used for possible higher total yield of relaycropping system farming on this histosol.

The competition index generating function was basically developed and extended from the proposed yield per plant vs. density model. With respect to peanut yield (TDM or pod yield) per plant, the function was expressed as

$$y_p = y_{arp} + (y_{op} - y_{arp})e^{-(x_{cp}/X_{cp} + x_{cc}/X_{cc})},$$

where subscript p (in y_p, y_{arp}, and y_{op}) refers to peanut, whereas y, y_{ar}, y_o are as previously defined. The x_{cp} and x_{cc} are competitive peanut and corn densities where each is based on competitive peanut area ($PDMAX^2$). Thus, X_{cc} and X_{pc} are the respective competitive density constants. With generally no interaction between x_{cp} and x_{cc} in affecting y_p, the competition index of corn to peanut, $CI_{c\ to\ p}$ (equivalency of corn plants to one peanut plant in giving equal effect

to peanut yield per plant), was computed as X_{cc}/X_{cp}. Similar procedures were used in computing the competition index of peanut to corn, $CI_{p \text{ to } c}$ (equivalency of peanut plants to one corn plant in giving equal effect to corn yield per plant). There were also no interactions between competitive corn and peanut densities in affecting corn yields per plant.

With respect to TDM and reproductive yields per plant, all $CI_{p \text{ to } c}$ values were much higher than those of $CI_{c \text{ to } p}$ in all environments and cycles. This suggests that corn plants were more effective than the peanut in affecting each other's individual total and reproductive growth.

Under the N-fertilized environments, the $CI_{c \text{ to } p}$ ratios with respect to TDM and pod yields among three cycles of peanut intercropping and intercrop-related relaycropping [monocropping-(I) was used for corn competitive density (x_{cc}) = 0 plants $PDMAX^{-2}$ as one of the input data in the analysis] were 0.18:1 to 0.64:1 and 0.07:1 to 0.13:1 corn:peanut, respectively. It is concluded that under the N-fertilized environment, peanut yield per plant was reduced more by corn than by intercrop peanut itself, and this reduction was then more prominant in the relaycropping, apparently due to suppression by low nutrient status at relaycropping time. This supports the conclusion presented earlier. There were some indications that N would be lost from applied N fertilizer (urea) even without corn cropping. With this consideration, the $CI_{c \text{ to } p}$ ratios (with respect to TDM and pod yield) of relaycrop-related relaycroppings [monocropping-(R) was used

for corn competitive density (x_{cc}) = 0 plants PDMAX^{-2}] were > 2:1 (cycles 1 and 3). Both these $CI_{c \text{ to } p}$ values and consideration of different physical plant structures (corn vs. peanut) support the earlier suggestion that relaycrop peanut was probably less physically affected by limiting light (less etiolation) than intercrop peanut. As revealed by $CI_{c \text{ to } p}$ values, reductions in peanut TDM and pod yields per plant by corn in non-N-fertilized inter- and relaycropping were also indicated. The magnitude of absolute peanut yield reduction should increase with increasing mixture density (especially corn density).

The $CI_{p \text{ to } c}$ values with respect to corn TDM and ear yields for intercropping were generally lower than those of relaycropping. Furthermore, the above respective values among all cycles were consistently low (1.5:1 to 3.7:1 peanut:corn) in the non-N-fertilized intercropping, and were much higher in the relaycropping environments. It is concluded that corn growth and yield were affected (reduced) by peanut in the intercropping environment, but little in the relaycropping situations. The relative reduction was increased in the non-N-fertilized intercropping. Furthermore, the magnitude of competition experienced by corn should increase with increasing mixture density (especially increase in peanut density). However, in the cycle 2 area previously grown to corn (lowest C:N), the $CI_{p \text{ to } c}$ values revealed less peanut effect on corn in N-fertilized intercropping. The above findings and conclusion were in agreement with those based on the earlier methods of analysis.

It was postulated that if the ratio [(competitive density constant of crop 1):(competitive density constant of crop 2)] in affecting yield of crop 1 is equal to the ratio in affecting yield of crop 2, then those two component crops are actually not differentiating the environment. Based on the above postulation, the environmental differentiation index (EDI) was then developed.

The EDI values with respect to TDM and reproductive yields among all cycles in non-N-fertilized intercropping plots were close to unity (0.5 to 2.8), indicating peanut and corn growth and yield were occurring in the same resource environment. The stunted corn growth permitted ample light to reach the understory peanut, and thus they were competing for nutrients and other edaphic growth factors in the same environment. In the above environment, however, corn was considered to receive more resources than did peanut ($CI_{p \text{ to } c} > CI_{c \text{ to } p}$). In the N-fertilized intercropping environment, the EDI values were higher (6.3 to 51.5) than those in the above. Thus, peanut and sweetcorn were differentiating the intercropping environment. The N-fertilized overstory corn (heavier canopy) was in a high-light regime environment, whereas the understory peanut was in a low-light environment. Consequently, corn had a better environment than peanut ($CI_{p \text{ to } c} > CI_{c \text{ to } p}$). By considering unavoidable N loss (from applied urea) with time even without corn cropping, the EDI values with respect to TDM and reproductive yields for N-fertilized relaycropping plots of all cycles were generally very large. This indicates that under the environment of tropical peat soil, the environmental differentations for sweetcorn and peanut growth and

yield were obviously due to different time-related growth factors and soil-N regimes. In the non-N-fertilized relaycropping, it is suggested that the differentiation was mainly due to different time-related growth factors and non-N nutrient regimes. In both N- and non-N-fertilized relaycropping of all cycles, corn environments were better than those of peanut ($CI_{p \text{ to } c} > CI_{c \text{ to } p}$).

The monocrop TDM and reproductive yields of corn and peanut [monocropping-(I)] at 5.3 and 20.0 plants m^{-2}, respectively, at each N-fertilization level were used as the denominators or bases for land equivalent ratio (LER) and area-time equivalency ratio (ATER) computations. The above respective plant densities are commonly used in the region (Malaysian environment). Thus the relative biological efficiencies at other densities could then be compared against a realistic base density of the monocrops.

The LER (for inter- and relaycropping) and ATER (intercropping) values with respect to TDM yields were generally > 1, and furthermore were generally increased with increasing density. This indicates that the resource exploitation for total growth was more space efficient (relative to each crop standard monocropping) with inter- or relaycropping and with higher plant densities. However, relaycropping was generally space-time inefficient compared to monocropping (ATER < 1). Since the low absolute reproductive yields of both corn and peanut might always be uneconomic in the non-N-fertilized plots, the LER and ATER of N-fertilized plots should have more meaningful and practical value. Thus, only LER and ATER based on reproductive yield and N fertilization were emphasized. Generally, peanut and sweetcorn

inter- and relaycropping were more space efficient (LER > 1) in reproductive yield relative to either monocroppings (at standard density). However when time element (area-time basis) was considered, generally relaycroppings were no longer efficient (ATER < 1). On the other hand, intercroppings were generally still space-time efficient (ATER > 1) or comparable (ATER ≈ 1) to monocroppings. However, in cases where inefficiencies were prominant (ATER << 1), the levels of efficiency were similar to those when time was not considered (LER). These differentials were mainly due to time element and very low relaycrop peanut yield. Intercropping had a shorter cropping system duration (100 days) and fewer unused time (20 ha-days) than did relaycropping [153 day cropping system duration and (53 + 72) ha-days unused time]. Thus, if time was critical, relaycropping should only be done for other special reason(s).

The general trends of relationships among LER, ATER, and component crop contributions were discussed by using values that were obtained from averaging over five peanut densities at each of sweetcorn (base crop) density x cropping system x N combinations. The average LER values for N-fertilized intercropping plots among all cycles at 2.7 to 5.3 corn plants m^{-2} (LER = 1.20 to 1.38) were generally higher than those at 13.3 corn plants m^{-2}. On the other hand, the higher LER values were observed at 5.3 to 13.3 corn plants m^{-2} (LER = 1.11 to 1.48) vs. 2.7 corn plants m^{-2} in the N-fertilized relaycropping plots. Peanut contributions to LER were quite substantial (50 to 55%) in the N-fertilized intercropping at low corn

density (2.7 plants m^{-2}). However, at higher corn densities (5.3 and 13.3 corn plants m^{-2}) (in inter- or relaycropping), corn contributions to LER were evidently important (55 to 86%). This trend was also observed in relaycropping involving low corn density (71 to 78% corn contribution). It is concluded, therefore, that in order for the system to be biologically space efficient relative to the respective monocropping, either one component crop should approach its monoculture yield or that both crops should be reasonably productive.

It was considered that optimum corn density was approximately 5.3 plants m^{-2}. It was also predicted that by reapplying N and other nutrients immediately after sweetcorn harvest, the relaycrop peanut yield could be increased to a level that would be comparable to the monocropping, while the corn yield would not be affected by relayplanted peanut. By assuming that the relaycrop peanut yield would be 75 to 100% of monocropping, the new calculated LER of relaycropping at 5.3 corn plants m^{-2} in cycle 1, 2, and 3 would be 1.85 to 2.05, 1.76 to 1.99, and 1.79 to 2.04, respectively. The respective predicted new ATER would then be 1.02 to 1.19, 0.99 to 1.15, and 1.02 to 1.18 (the respective original ATER values were 0.80, 0.62, and 0.76). Therefore, little extra input, especially N fertilization, would increase the productivity and efficiency (LER) of relaycropping at optimum corn density. The ATER values in relaycropping on a tropical peat could still be better or at least comparable to those of monocroppings.

The plant response (TDM and reproductive yield per plant and per unit area) vs. density models developed in this study were found to be

applicable to different environments [mono-, inter-, and relaycropping at two N levels (0 vs. 150 kg ha^{-1})] of all cycles. They were also applicable to two different types of crop plants [corn (C4) and peanut (C3)] differing in growth habit, structure, and physiological requirements. The model usefulness was due to the postulated physiological relationships and to the biologically meaningful parameters contained in the models. It is concluded that the models can likely be applied to other environments than those of tropical peat conditions, and to other crop plants. Consequently, the competition and environmental differentiation indices could also be used for the other crop plants in associative cropping.

APPENDIX A
GLOSSARY

Additive series = Mixtures of two crops that are formed by any combination of two densities of the respective component crops in which the total population density might be higher than that of either monoculture.

Aggressivity = Measure of relative yield increase in species 1 from a replacement series mixture compared to that in species 2.

Area-time equivalency ratio (ATER) = The ratio of area-time required in monoculture to area-time used by intercrop in producing the same quantities of all component crops.

Biological efficiency = The efficiency in terms of yield of crop mixture in utilizing growth factors compared to either component monoculture.

Biological efficiency indices = Indices (LER and ATER) used to express biological efficiency of the mixture.

CDMAX = Distance between two corn plants where competition in a good growth environment disappears or becomes negligible.

Cocropping = Growing two crops together within the same row, for example, soybean and sweetcorn.

Combining compatibility = Discrimination by component crops in the use of growth factors for maximum exploitation of the environmental resources.

Competition = Forced sharing among plants of available environmental resources. The intra- and interspecific competition refer to within and between species, respectively.

Competition index = See equivalency factor. However, the equivalency factor for this index is obtained from the competitive density constants of component crops in a mixture.

Competitive advantage = The average of absolute increase in yield for species 1 in a mixture over its monoculture and the reduction of yield of species 2 from its monoculture.

Competitive density constant = Required plants per competitive area in reducing the maximum differentiable yield portion per plants to its 37% or e^{-1}.

Competitive-density index = Resulting value from the linear relationship between the logarithm of total yield per plant vs. the logarithm of density, which determines yield per unit area vs. density relationship, e.g., increasing, plateau, or decreasing.

Competitive depression = The half decrease of total yields of species 1 and 2 in a mixture from the total yields of species 1 and 2 monocultures.

Competitive ratio = Measurement of the relative number of times by which one component crop in association is more competitive than the other.

Crop intensity index (CII) = The actual area-time devoted for production of crop or mixture with respect to total area-time available during a specified time period, usually one year.

Crowding = Summation of crowding of independent plants within a planting pattern which is attributed to each plant as a function of its distance from the target plant.

Degree of environmental differentiation = Extent of environmental differentiation among component crops in a given environment.

Diallel design experiment = Crops grown together as 1:1 binary mixtures in all combinations along with pure cultures, at a constant overall density.

Differentiable response ratio (DRR) = The ratio of a maximum differentiable yield per plant to an apparent residual (minimum response) per plant in a given environment.

Effect of crowding on grain yield (E) = The effect that reduces a fixed fraction yield per plant per unit change in crowding.

Efficiency indices = Indices, which indicate the biological efficiencies, normally are expressed as LER and ATER.

Environmental differentiation = see niche differentiation.

Environmental differentiation index (EDI) = Measure of the degree of environmental differentiation for associative component crops.

Equivalency = See plant equivalency.

Equivalency error = Either over or under estimate of equivalency factor.

Equivalency factor = Plant number required of species 1 that is equivalent to one plant of species 2 in equally affecting yield per plant of species 2.

General space constant = A power constant that is derived from the asymptotic relationship between yield per plant vs. space per plant.

Index of apparent mutual stimulation or inhibition = The average value from the relative yields (yield per plant in mixture divided by its monoculture) of species 1 and 2 in association.

Index of competitive ability = Competitive ability of species 1 as indicated by the species 2 yield reduction (from yield of species 2 vs. yield of species 1 linear relationship).

Intercropping = Growing two or more crops simultaneously where one or more crops are planted in rows.

Intraspecific competition stress = Ratio of change in reciprocal yield per plant with respect to density increase to its value without competition.

Land equivalent ratio (LER) = The relative land area under sole crops that is required to produce the yields achieved in mixture.

Law of constant final yield = Constant yield per unit area resulting from the product of yield per plant and density at higher density region.

Logistic growth curve = The sigmoid shape of the relationship between the growth vs. time. The growth phases (in sequence with increasing time) are exponential, linear, dampened exponential, and steady state. The governing factor is that the relative growth rate decreases with time in a "reverse sigmoid" trend.

Monocropping = One crop grown in a given same land area.

Monocropping-(I) = Correspondence of monocrop planting date with that of an intercrop.

Monocropping-(R) = Correspondence of monocrop planting date with that of a relaycrop.

Niche differentiation = Result of intraspecific competition being greater than interspecific competition because resources among component crops in a mixture are used at different times and/or levels.

Nitrogen use efficiency = Biomass produced or carbon dioxide fixed per unit of nitrogen in the plant.

Plant equivalency or plant number equivalency = See equivalency factor.

Plant population or plant density = Plant number per unit ground area.

PDMAX = Distance between two peanut plants where competition in a good growth environment disappears or becomes negligible.

Ratio of the competition coefficients = See equivalency factor.

Relative crowding coefficient = A measure of the deviation of yield from the expected of a species in a replacement series mixture.

Relative yield total (RYT) = The sum of the relative yields of two species in a mixture, where relative yield for each species is defined as the ratio of yield per plant in a mixture to that in a monoculture.

Relaycropping = Growing two or more crops where the second crop(s) is planted after the first crop has reached its reproductive growth stage but before its harvest.

Replacement series = A mixture of two crops that are formed by replacing a proportion of one crop with an equivalent density of another crop.

Strength of competition = The competitiveness of species 1 relative to species 2 in affecting the yield per plant of species 2 or vice versa.

Yield advantage = General term used for expressing the advantage of the mixture relative to total yield of the component crops grown in monoculture.

Yield proportion = The percentage of a component crop's contribution in the total LER or ATER of the mixture.

APPENDIX B

PEANUT AND SWEETCORN TOTAL DRY MATTER AND REPRODUCTIVE YIELDS, LAND EQUIVALENT RATIO, AND AREA-TIME EQUIVALENCY RATIO AT DIFFERENT NITROGEN RATES, CROPPING SYSTEMS, AND PLANTING DENSITIES

Table B-1. Peanut total dry matter (TDM) and pod yield per plant at different nitrogen rates, density-systems, and peanut densities in three cycles of experimentation on a Malaysian histosol.

Nitrogen (N) (kg ha^{-1})	System-corn density° (S-C)	TDM yield per plant — Peanut density (P) (plants m^{-2})					Pod yield per plant — Peanut density (P) (plants m^{-2})				
		5	10	20	40	80	5	10	20	40	80
		g plant^{-1}									
		cycle 1									
0	MAI	25.5	13.3	10.6	8.1	5.4	10.1	5.7	3.9	2.7	2.0
	MBI	20.6	11.6	12.5	5.9	5.8	7.9	5.2	4.7	2.1	2.2
	MCI	19.7	10.5	10.1	6.8	5.5	8.8	5.1	4.3	2.5	1.9
	MAR	8.2	10.8	4.5	4.1	3.5	3.0	3.8	1.7	0.8	0.7
	MBR	13.1	12.7	6.3	5.5	3.6	4.6	4.6	4.0	2.0	0.9
	MCR	8.6	5.8	4.2	4.6	3.0	3.9	2.2	1.5	1.3	0.9
	MOI	46.9	23.1	17.1	11.8	5.3	17.5	11.5	8.0	3.8	2.0
	MOR	20.6	11.8	13.4	6.5	4.9	9.8	4.8	5.5	2.3	1.3
150	MAI	61.8	32.7	23.4	19.9	11.9	16.8	13.6	7.7	4.9	3.5
	MBI	22.3	23.3	15.8	14.6	9.8	18.8	7.7	4.7	5.5	2.1
	MCI	34.1	26.4	16.6	11.5	8.9	9.0	6.8	4.4	3.6	2.1
	MAR	17.8	13.3	7.3	4.8	3.3	6.8	6.6	2.2	1.8	1.4
	MBR	17.2	15.1	13.5	6.3	5.3	7.1	9.3	4.3	3.1	2.3
	MCR	22.7	15.3	10.3	6.7	4.3	9.7	7.7	4.9	3.1	2.2
	MOI	69.5	48.2	28.8	18.7	13.4	35.5	20.0	11.2	6.9	5.4
	MOR	26.2	22.8	14.1	6.2	6.4	16.0	10.1	3.6	2.9	1.5
LSD (0.05)[1]		- - - - - - - -		13.3	- - - - - - - -		- - - - - - - -		6.4	- - - - - - - -	
		cycle 2									
0	MAI	21.6	19.9	14.8	7.2	5.2	9.4	6.5	4.7	2.2	1.8
	MBI	21.4	13.9	9.8	8.9	4.9	10.9	7.0	2.8	2.5	1.6
	MCI	16.2	11.5	11.2	7.4	4.5	6.6	5.0	2.8	2.7	1.9
	MAR	6.3	5.7	3.6	2.9	2.7	2.9	1.6	1.1	0.6	0.5
	MBR	12.4	7.3	4.4	3.1	2.7	3.0	2.9	1.6	0.9	0.7
	MCR	5.3	3.4	3.8	3.0	2.2	1.9	1.2	0.8	0.6	0.4

	MOI	45.3	34.8	22.3	13.2	5.8	20.8	13.8	5.8	3.6	2.1
	MOR	20.7	14.5	7.9	6.1	3.6	7.7	5.2	2.1	1.7	1.0
150	MAI	32.1	26.9	20.2	17.1	8.8	13.3	10.2	8.6	4.9	3.2
	MBI	31.4	20.2	15.9	10.8	9.6	15.2	7.8	4.6	3.5	1.7
	MCI	17.4	17.4	13.9	9.6	7.2	6.3	4.7	4.4	2.1	1.7
	MAR	16.9	8.8	7.6	4.9	3.8	6.0	3.1	2.3	1.3	1.1
	MBR	17.0	10.5	7.3	4.2	2.5	5.2	3.1	2.0	1.0	0.8
	MCR	13.4	9.3	6.2	5.8	3.7	5.0	3.2	1.8	1.5	0.5
	MOI	67.0	53.7	29.9	21.9	14.0	27.3	17.7	11.8	8.2	5.4
	MOR	33.6	23.0	12.7	8.0	4.9	13.2	8.6	4.5	2.1	1.2
LSD (0.05)[1]		- - - - - - - -		8.7	- - - - - - - -		- - - - - - - -		4.4	- - - - - - - -	
		----------				cycle 3			----------		
0	MAI	13.7	10.7	11.4	6.9	7.7	5.9	4.9	3.8	2.3	2.1
	MBI	14.5	12.4	8.9	5.9	5.5	5.5	4.8	2.8	1.7	1.3
	MCI	12.1	10.6	8.8	6.9	5.9	4.7	3.1	2.3	1.8	1.4
	MAR	13.9	11.9	8.2	5.4	4.0	6.9	6.6	3.8	2.3	1.6
	MBR	11.5	9.7	6.1	5.8	4.3	6.8	5.1	2.5	2.4	1.7
	MCR	20.4	9.8	6.8	4.3	4.5	9.0	3.4	3.5	1.6	1.2
	MOI	38.7	29.1	15.6	10.7	8.5	16.7	10.2	4.0	3.5	2.4
	MOR	24.3	18.0	8.1	5.7	5.6	10.8	7.6	3.2	2.5	2.2
150	MAI	23.3	19.3	14.0	11.8	9.8	10.0	7.5	4.4	3.8	2.6
	MBI	19.1	14.2	10.4	7.6	7.1	7.6	5.6	2.9	1.9	2.0
	MCI	9.7	13.4	6.8	5.6	7.3	3.3	3.2	2.3	1.7	1.7
	MAR	16.5	9.8	6.6	5.1	3.6	5.2	4.3	2.8	2.3	1.2
	MBR	15.1	9.1	7.2	5.0	2.3	6.7	3.4	2.8	2.0	1.1
	MCR	32.1	11.0	7.2	5.8	5.3	9.4	4.6	2.7	1.8	1.3
	MOI	46.2	40.2	23.6	15.1	11.6	17.8	11.7	8.2	4.3	3.1
	MOR	25.6	18.2	9.6	7.8	6.9	15.2	7.6	4.2	3.2	1.8
LSD (0.05)[1]		- - - - - - - -		7.9	- - - - - - - -		- - - - - - - -		3.2	- - - - - - - -	

°: MAI = Intercropping at 2.7 corn plants m^{-2}; MBI = Intercropping at 5.3 corn plants m^{-2}; MCI = Intercropping at 13.3 corn plants m^{-2}; MAR = Relaycropping at 2.7 corn plants m^{-2}; MBR = Relaycropping at 5.3 corn plants m^{-2}; MCR = Relaycropping at 13.3 corn plants m^{-2}; MOI = Monocropping that corresponds to interplanting date; MOR = Monocropping that corresponds to relayplanting date.

¶: LSD for comparison between two C-S yields at same N x P combination.

Table B-2. Sweetcorn total dry matter (TDM) and ear yield per plant at different nitrogen rates, cropping systems, peanut densities, and corn densities in three cycles of experimentation on a Malaysian histosol.

Nitrogen (N) (kg ha^{-1})	Cropping system (CS)	Peanut density (P) (plants m^{-2})	TDM yield per plant			Ear yield per plant		
			Corn density (C)(plants m^{-2})			Corn density (C)(plants m^{-2})		
			2.7	5.3	13.3	2.7	5.3	13.3
			g $plant^{-1}$					
			cycle 1					
0	Monocropping (M)	0	89.9	39.9	18.1	94.7	24.8	6.5
	Intercropping (I)	5	62.1	32.6	17.3	45.6	14.5	5.1
		10	36.2	25.6	11.5	11.2	10.8	5.7
		20	25.6	15.3	12.7	19.1	5.2	6.6
		40	24.4	22.8	9.2	18.7	10.1	2.2
		80	20.7	10.6	12.9	15.6	5.8	3.8
		Mean (MI)	33.8	21.4	12.7	22.0	9.3	4.7
	Relaycropping (R)	5	92.1	43.4	23.1	88.1	28.3	9.2
		10	96.2	46.5	17.8	75.0	35.8	6.3
		20	102.9	65.0	21.7	97.8	38.9	7.4
		40	65.9	52.6	17.1	65.0	31.5	4.4
		80	57.2	42.7	21.5	54.7	32.6	6.7
		Mean (MR)	82.9	50.0	20.3	76.1	33.3	6.8
150	Monocropping (M)	0	192.3	111.6	88.5	230.5	145.9	44.4
	Intercropping (I)	5	159.7	117.6	47.3	159.4	130.6	35.0
		10	219.7	95.2	44.6	231.6	100.9	30.6
		20	114.3	79.1	66.7	158.3	97.7	48.9
		40	90.9	62.4	50.0	110.8	65.8	34.9
		80	108.7	77.7	43.6	165.9	102.3	39.1
		Mean (MI)	138.7	86.4	50.4	165.2	99.5	37.7

	Relaycropping (R)	5	185.2	128.3	55.7	215.9	159.4	39.2
		10	173.3	101.3	64.0	243.1	124.4	49.4
		20	214.2	120.7	47.2	270.4	159.8	48.2
		40	163.1	109.2	53.3	230.0	137.3	42.8
		80	156.7	136.1	55.0	223.3	161.9	36.0
		Mean (MR)	178.5	119.1	55.0	236.5	148.6	43.1
LSD (0.05):	(1) M vs. "MI or MR" at same N x C			(1) 32.9			(1) 34.1	
	(2) MI vs. MR at same N x C			(2) 19.1			(2) 19.7	
	(3) Between two P values at same N x CS x C (only for I and R)			(3) 32.3			(3) 39.5	
			---------- cycle 2 ----------					
0	Monocropping (M)	0	117.0	92.4	42.6	131.9	85.8	29.4
	Intercropping (I)	5	83.4	65.3	39.8	84.4	48.9	23.4
		10	72.6	47.5	36.8	42.5	23.3	7.3
		20	69.1	42.0	41.6	62.2	28.4	12.4
		40	62.5	43.3	35.2	55.0	39.5	16.2
		80	63.7	48.4	33.0	50.2	19.8	14.1
		Mean (MI)	70.3	49.3	37.3	58.8	31.9	14.7
	Relaycropping (R)	5	129.1	72.7	40.2	138.1	66.6	22.3
		10	105.3	61.5	40.9	109.2	64.8	19.4
		20	115.1	88.2	43.9	130.3	58.6	20.4
		40	128.0	95.0	41.6	124.1	77.6	17.8
		80	125.8	75.0	40.2	141.5	55.8	16.3
		Mean (MR)	121.2	78.5	41.4	128.6	64.7	19.2
150	Monocropping (M)	0	166.2	116.9	59.9	168.2	124.6	53.6
	Intercropping (I)	5	160.6	114.2	66.3	162.8	100.0	51.6
		10	162.6	107.5	63.4	176.2	113.3	42.6
		20	108.5	103.5	55.4	109.1	100.3	38.5
		40	164.6	102.3	66.2	172.5	113.9	53.8
		80	121.1	100.7	60.7	142.8	114.8	51.4
		Mean (MI)	143.5	105.6	62.4	152.7	108.5	47.6

Table B-2--continued.

Nitrogen (N) (kg ha^{-1})	Cropping system (CS)	Peanut density (P) (plants m^{-2})	TDM yield per plant: Corn density (C)(plants m^{-2}) 2.7	5.3	13.3	Ear yield per plant: Corn density (C)(plants m^{-2}) 2.7	5.3	13.3
	Relaycropping (R)	5	184.9	120.5	67.7	182.2	127.8	53.7
		10	204.2	105.0	58.5	194.1	122.6	51.6
		20	144.7	108.6	48.0	161.6	116.6	49.4
		40	138.9	124.3	70.3	176.9	135.0	59.8
		80	155.2	86.3	58.0	204.1	81.6	41.9
		Mean (MR)	165.6	108.9	60.5	183.7	116.7	51.3
LSD (0.05):	(1) M vs. "MI or MR" at same N x C			(1) 27.9			(1) 32.3	
	(2) MI vs. MR at same N x C			(2) 16.1			(2) 18.6	
	(3) Between two P values at same N x CS x C (only for I and R)			(3) 29.4			(3) 34.3	
			cycle 3					
0	Monocropping (M)	0	117.8	67.8	36.2	120.2	64.2	14.4
	Intercropping (I)	5	67.1	34.4	22.8	47.0	19.7	6.4
		10	46.8	57.1	26.6	28.9	14.0	6.4
		20	53.5	26.7	22.0	40.4	9.2	4.9
		40	33.4	29.5	17.9	24.2	8.2	3.4
		80	46.0	32.7	23.9	18.2	9.4	6.7
		Mean (MI)	49.4	36.1	22.6	31.7	12.1	5.6
	Relaycropping (R)	5	112.1	72.8	23.6	143.7	58.0	7.1
		10	117.6	79.5	32.4	154.1	66.3	16.0
		20	113.6	60.7	32.4	134.2	43.9	13.5
		40	120.3	70.6	29.1	142.4	58.8	10.1
		80	107.7	70.8	26.1	117.2	54.6	9.5
		Mean (MR)	114.3	70.9	28.7	138.3	56.3	11.2

150	Monocropping (M)	0	160.1	102.3	63.9	201.9	109.1	39.4
	Intercropping (I)	5	136.7	90.1	51.2	152.2	80.9	27.5
		10	131.2	90.4	49.6	147.4	90.4	26.0
		20	117.9	92.2	43.6	117.5	87.7	22.3
		40	121.9	94.1	51.5	118.2	64.8	24.3
		80	106.8	75.3	46.5	128.1	71.6	25.1
		Mean (MI)	122.9	88.4	48.5	132.7	79.1	25.0
	Relaycropping (R)	5	164.9	99.2	58.9	209.6	91.2	35.8
		10	161.0	96.6	55.6	224.6	118.2	35.9
		20	121.3	80.4	50.8	178.1	91.2	35.9
		40	145.6	105.3	51.5	208.8	114.2	38.2
		80	145.9	118.1	64.5	178.2	110.3	43.1
		Mean (MR)	147.7	99.9	56.3	199.8	105.1	37.8

LSD (0.05): (1) M vs. "MI or MR" at same N x C — (1) 22.5 — (1) 31.6
(2) MI vs. MR at same N x C — (2) 12.9 — (2) 18.2
(3) Between two P values at same N x CS x C (only for I and R) — (3) 27.0 — (3) 38.8

Table B-3. Peanut total dry matter (TDM) and pod yield per hectare at different nitrogen rates, density-systems, and peanut densities in three cycles of experimentation on a Malaysian histosol.

Nitrogen (N)	System-corn density	TDM yield per ha					Pod yield per ha				
		Peanut density (P)(plants m^{-2})					Peanut density (P)(plants m^{-2})				
(kg ha^{-1})	(S-C)	5	10	20	40	80	5	10	20	40	80
		kg ha^{-1}									
		cycle 1									
0	MAI	1277	1333	2135	3227	4383	505	570	776	1065	1613
	MBI	1032	1157	2501	2336	4711	396	523	939	822	1758
	MCI	987	1050	2032	2704	4481	442	511	861	984	1548
	MAR	410	1081	908	1620	2820	152	384	342	329	576
	MBR	653	1270	1260	2181	2878	230	459	802	809	795
	MCR	432	581	849	1818	2421	199	219	312	529	726
	MOI	2346	2304	3438	4700	4299	878	1152	1605	1532	1654
	MOR	1032	1176	2691	2580	3998	490	481	1106	944	1041
150	MAI	3092	3272	4691	7932	9662	841	1358	1546	1977	2873
	MBI	1117	2332	3166	5826	7917	939	767	945	2195	1706
	MCI	1706	2644	3319	4574	7171	452	680	890	1419	1741
	MAR	891	1330	1469	1913	2671	340	657	443	720	1126
	MBR	859	1509	2716	2526	4326	355	925	855	1237	1847
	MCR	1134	1527	2073	2660	3456	485	771	987	1239	1813
	MOI	3476	4819	5782	7440	10869	1778	2001	2245	2748	4386
	MOR	1310	2279	2837	2483	5178	802	1008	719	1144	1252
LSD (0.05)‡				1835					722		
		cycle 1									
0	MAI	1082	1995	2979	2852	4240	470	652	953	883	1487
	MBI	1069	1395	1961	3527	4020	549	703	555	994	1267
	MCI	810	1145	2242	2932	3624	332	500	575	1063	1543
	MAR	313	574	717	1178	2217	149	164	216	237	439
	MBR	623	735	892	1260	2182	150	290	337	386	568
	MCR	266	341	765	1202	1808	96	123	160	254	314
	MOI	2265	3481	4482	5246	4728	1041	1377	1166	1446	1709
	MOR	1037	1449	1579	2422	2926	386	514	417	662	809

150	MAI	1608	2686	4054	6826	7135	666	1016	1718	1961	2626
	MBI	1572	2016	3200	4316	7755	761	779	924	1405	1409
	MCI	870	1741	2784	3839	5788	313	470	885	842	1413
	MAR	848	876	1518	1971	3070	302	313	468	541	931
	MBR	851	1047	1466	1670	2064	262	313	405	408	624
	MCR	672	934	1249	2312	2968	251	323	359	621	420
	MOI	3354	5363	5990	8738	11350	1367	1769	2363	3278	4395
	MOR	1682	2298	2545	3201	3960	663	860	895	845	962
LSD 90.05)‡		- - - - - - - -		1424	- - - - - - - -		- - - - - - - -		596	- - - - - - - -	
						cycle 1					
0	MAI	687	1069	2295	2741	6268	298	497	759	937	1658
	MBI	724	1236	1776	2338	4465	276	485	570	700	1024
	MCI	605	1060	1765	2748	4744	235	306	467	746	1131
	MAR	697	1193	1642	2153	3237	347	665	760	915	1284
	MBR	576	969	1234	2336	3511	342	508	506	940	1387
	MCR	1023	976	1374	1724	3666	453	345	715	650	949
	MOI	1935	2909	3129	4265	6902	835	1024	801	1398	1953
	MOR	1218	1802	1616	2276	4543	540	760	633	1000	1751
150	MAI	1168	1927	2810	4704	7965	501	752	891	1505	2093
	MBI	956	1420	2082	3041	5756	382	559	586	771	1628
	MCI	484	1341	1368	2222	5926	164	319	454	672	1405
	MAR	826	977	1327	2026	2949	261	434	556	924	987
	MBR	756	909	1449	1981	1874	334	345	570	791	880
	MCR	1606	1105	1454	2298	4272	475	458	536	735	1017
	MOI	2312	4020	4734	6027	9359	893	1174	1654	1695	2524
	MOR	1281	1816	1920	3102	5576	760	760	833	1260	1471
LSD (0.05)‡		- - - - - - - -		1323	- - - - - - - -		- - - - - - - -		443	- - - - - - - -	

† MAI = Intercropping at 2.7 corn plants m^{-2}; MBI = Intercropping at 5.3 corn plants m^{-2}; MCI = Intercropping at 13.3 corn plants m^{-2}; MAR = Relaycropping at 2.7 corn plants m^{-2}; MBR = Relaycropping at 5.3 corn plants m^{-2}; MCR = Relaycropping at 13.3 corn plants m^{-2}; MOI = Monocropping that corresponds to interplanting date; MOR = Monocropping that corresponds to relayplanting date.

‡ LSD for comparison between two S-C yields at same N x P combination.

Table B-4. Sweetcorn total dry matter (TDM) and ear yield per hectare at different nitrogen rates, cropping systems, peanut densities, and corn densities in three cycles of experimentation on a Malaysian histosol.

Nitrogen (N) (kg ha^{-1})	Cropping system (CS)	Peanut density (P) (plants m^{-2})	TDM yield per ha: Corn density (C)(plants m^{-2}) 2.7	5.3	13.3	Ear yield per ha: Corn density (C)(plants m^{-2}) 2.7	5.3	13.3
			kg ha^{-1}					
			cycle 1					
0	Monocropping (M)	0	2397	2130	2413	2525	1321	871
	Intercropping (I)	5	1657	1740	2312	1217	775	683
		10	964	1416	1532	300	575	758
		20	682	817	1697	508	275	875
		40	651	1216	1235	500	542	292
		80	551	567	1726	417	308	508
		Mean (MI)	901	1151	1700	588	495	623
	Relaycropping (R)	5	2455	2313	3085	2350	1508	1233
		10	2563	2478	2377	2000	1908	842
		20	2745	3466	2926	2608	2075	992
		40	1760	2806	2284	1733	1683	592
		80	1526	2276	2869	1458	1742	892
		Mean (MR)	2210	2668	2708	2030	1783	910
150	Monocropping (M)	0	5127	5952	11808	6148	7785	5919
	Intercropping (I)	5	4258	6272	6304	4250	6967	4667
		10	5859	5076	5953	6175	5383	4078
		20	3047	4217	8889	4222	5211	6517
		40	2425	3327	6671	2956	3511	4655
		80	2898	4146	5810	4425	5455	5208
		Mean (MI)	3697	4608	6725	4405	5305	5025

	Relaycropping (R)	5	4939	6842	7425	5758	8500	5225
		10	4621	5406	8542	6483	6633	6589
		20	5712	6441	6297	7211	8522	6433
		40	4348	5828	7105	6133	7322	5708
		80	4179	7261	7343	5956	8633	4800
		Mean (MR)	4760	6355	7342	6308	7922	5751

LSD (0.05): (1) M vs. "MI or MR" at same N x C — (1) 1733 — (1) 1454
(2) MI vs. MR at same N x C — (2) 1000 — (2) 839
(3) Between two P effects at same N x CS x C (only for I and R) — (3) 1748 — (3) 1767

cycle 2

0	Monocropping (M)	0	3121	4931	5680	3519	4577	3921
	Intercropping (I)	5	2226	3485	5311	2250	2608	3125
		10	1936	2536	4906	1133	1244	967
		20	1843	2242	5554	1658	1517	1650
		40	1666	2311	4699	1467	2108	2158
		80	1699	2583	4405	1338	1055	1883
		Mean (MI)	1874	2632	4975	1569	1707	1957
	Relaycropping (R)	5	3442	3879	5358	3683	3550	2975
		10	2808	3281	5464	2911	3458	2583
		20	3068	4706	5865	3475	3125	2717
		40	3413	5068	5554	3308	4142	2375
		80	3429	4003	5363	3775	2975	2175
		Mean (MR)	3232	4187	5521	3430	3450	2565
150	Monocropping (M)	0	4433	6235	7994	4485	6644	7144
	Intercropping (I)	5	4283	6089	8847	4342	5333	6883
		10	4336	5735	8454	4700	6044	5675
		20	2893	5523	7392	2908	5350	5133
		40	4390	5457	8832	4600	6075	7183
		80	3230	5373	8099	3808	6125	6858
		Mean (MI)	3826	5635	8325	4072	5785	6347

Table B-4--continued.

Nitrogen (N) (kg ha^{-1})	Cropping system (CS)	Peanut density (P) (plants m^{-2})	TDM yield per ha: Corn density (C)(plants m^{-2}) 2.7	5.3	13.3	Ear yield per ha: Corn density (C)(plants m^{-2}) 2.7	5.3	13.3
	Relaycropping (R)	5	4932	6429	9026	4858	6817	7163
		10	5445	5601	7807	5175	6542	6883
		20	3860	5791	6401	4308	6217	6592
		40	3703	6630	9374	4717	7200	7983
		80	4140	4604	7735	5442	4350	5592
		Mean (MR)	4416	5811	8069	4900	6225	6843
LSD (0.05):	(1) M vs. "MI or MR" at same N x C			(1) 1396			(1) 1532	
	(2) MI vs. MR at same N x C			(2) 806			(2) 884	
	(3) Between two P effects at same N x CS x C (only for I and R)			(3) 1644			(3) 1608	
			---------- cycle 3 ----------					
0	Monocropping (M)	0	3141	3616	4821	3207	3425	1920
	Intercropping (I)	5	1789	1834	3042	1253	1053	852
		10	1249	3051	3543	772	749	853
		20	1426	1425	2933	1077	492	658
		40	890	1572	2382	647	440	458
		80	1227	1746	3191	487	505	898
		Mean (MI)	1316	1926	3018	847	648	744
	Relaycropping (R)	5	2991	3884	3145	3832	3093	947
		10	3135	4243	4317	4108	3535	2138
		20	3030	3240	4323	3478	2343	1795
		40	3208	3766	3881	3798	3135	1350
		80	2872	3774	3479	3127	2913	1270
		Mean (MR)	3047	3781	3829	3689	3004	1499

150	Monocropping (M)	0	4271	5454	8528	5385	5817	5254
	Intercropping (I)	5	3645	4807	6823	4058	4313	3670
		10	3499	4821	6616	3931	4820	3473
		20	3145	4918	5819	3133	4677	2973
		40	3251	5017	6863	3153	3457	3245
		80	2847	4017	6199	3415	3822	3355
		Mean (MI)	3278	4716	6464	3538	4218	3343
	Relaycropping (R)	5	4397	5291	7861	5590	4867	4777
		10	4294	5153	7415	5990	6307	4787
		20	3235	4286	6772	4748	4864	4791
		40	3882	5619	6866	5568	6091	5088
		80	3890	6302	8602	4753	5884	5753
		Mean (MR)	3940	5330	7503	5330	5603	5039
LSD (0.05):	(1) M vs. "MI or MR" at same N x C			(1) 1085			(1) 1254	
	(2) MI vs. MR at same N x C			(2) 627			(2) 724	
	(3) Between two P effects at same N x CS x C (only for I and R)			(3) 1352			(3) 1465	

Table B-5. Land equivalent ratio (LER) and area-time equivalency ratio (ATER) with respect to TDM yield per hectare based on corresponding† monoculture TDM yields in the inter- and relaycropping systems in three cycles of experimentation on a Malaysian histosol.

Nitrogen	Corn density	System	LER					ATER				
			Peanut density (plants m^{-2})					Peanut density (plants m^{-2})				
(kg ha^{-1})	(plants m^{-2})	(cropping)	5	10	20	40	80	5	10	20	40	80
			Cycle 1									
0	2.7	Inter	1.23	0.98	0.91	0.96	1.25	1.10	0.90	0.85	0.90	1.20
		Relay	1.20	1.54	1.41	1.08	1.29	0.65	0.87	0.77	0.61	0.76
	5.3	Inter	1.26	1.17	1.11	1.07	1.36	1.09	1.03	1.03	0.95	1.31
		Relay	1.36	1.71	1.99	1.78	1.74	0.75	0.97	1.09	0.99	0.99
	13.3	Inter	1.38	1.09	1.29	1.09	1.76	1.19	0.96	1.15	0.98	1.61
		Relay	1.46	1.24	1.46	1.33	1.75	0.79	0.68	0.79	0.75	0.99
150	2.7	Inter	1.72	1.82	1.40	1.54	1.45	1.55	1.59	1.28	1.44	1.34
		Relay	1.22	1.18	1.37	1.11	1.06	0.67	0.65	0.75	0.61	0.59
	5.3	Inter	1.37	1.34	1.26	1.34	1.42	1.16	1.17	1.11	1.23	1.28
		Relay	1.40	1.22	1.55	1.32	1.62	0.76	0.68	0.87	0.73	0.90
	13.3	Inter	1.02	1.05	1.33	1.18	1.15	0.92	0.95	1.17	1.07	1.05
		Relay	0.95	1.04	0.89	0.96	0.94	0.54	0.58	0.51	0.55	0.53
			Cycle 2									
0	2.7	Inter	1.19	1.19	1.25	1.08	1.44	1.05	1.07	1.14	0.97	1.33
		Relay	1.24	1.06	1.14	1.32	1.56	0.67	0.58	0.62	0.72	0.88
	5.3	Inter	1.18	0.91	0.89	1.14	1.37	1.04	0.81	0.80	1.05	1.27
		Relay	1.06	0.88	1.15	1.27	1.27	0.59	0.48	0.63	0.69	0.73
	13.3	Inter	1.29	1.19	1.48	1.39	1.54	1.11	1.02	1.28	1.22	1.39
		Relay	1.06	1.06	1.20	1.21	1.33	0.57	0.57	0.65	0.66	0.74

150	2.7	Inter	1.44	1.48	1.33	1.77	1.36	1.25	1.28	1.20	1.57	1.21
		Relay	1.36	1.39	1.12	1.06	1.20	0.75	0.75	0.62	0.58	0.66
	5.3	Inter	1.44	1.29	1.42	1.37	1.54	1.25	1.11	1.24	1.19	1.37
		Relay	1.28	1.09	1.17	1.25	0.92	0.70	0.60	0.64	0.68	0.50
	13.3	Inter	1.37	1.38	1.39	1.54	1.52	1.14	1.17	1.20	1.32	1.32
		Relay	1.33	1.15	1.01	1.44	1.23	0.72	0.62	0.55	0.79	0.68
			- - - - - - - - - - - - - - - - Cycle 3 - - - - - - - - - - - - - - - -									
0	2.7	Inter	0.92	0.76	1.19	0.93	1.30	0.81	0.68	1.10	0.87	1.22
		Relay	1.31	1.41	1.49	1.53	1.38	0.73	0.79	0.85	0.86	0.78
	5.3	Inter	0.88	1.27	0.96	0.98	1.12	0.78	1.10	0.88	0.90	1.03
		Relay	1.37	1.51	1.29	1.59	1.55	0.76	0.83	0.73	0.90	0.88
	13.3	Inter	0.94	1.10	1.17	1.14	1.35	0.82	0.95	1.05	1.04	1.22
		Relay	1.18	1.23	1.33	1.21	1.25	0.69	0.69	0.75	0.68	0.72
150	2.7	Inter	1.36	1.30	1.33	1.54	1.52	1.19	1.13	1.18	1.39	1.38
		Relay	1.39	1.25	1.04	1.24	1.23	0.77	0.68	0.58	0.69	0.68
	5.3	Inter	1.29	1.24	1.34	1.42	1.35	1.12	1.06	1.16	1.24	1.20
		Relay	1.30	1.17	1.09	1.36	1.35	0.72	0.64	0.61	0.75	0.73
	13.3	Inter	1.01	1.11	0.97	1.17	1.36	0.85	0.95	0.83	1.01	1.21
		Relay	1.62	1.14	1.10	1.19	1.46	0.94	0.63	0.61	0.67	0.82

†: Corresponding monocrop corn and peanut densities.

Table B-6. Average° land equivalent ratio (LER) and area-time equivalency ratio (ATER) with respect to TDM yield per hectare based on corresponding† monoculture TDM yields, and their respective relative yield proportions in the inter- and relaycropping systems in three cycles of experimentation on a Malaysian histosol.

Nitrogen ($kg\ ha^{-1}$)	Corn density ($plants\ m^{-2}$)	System (cropping)	LER°			ATER°		
			LER	Peanut proportion	Corn proportion	ATER	Peanut proportion	Corn proportion
			Cycle 1					
0	2.7	Inter	1.06	0.65	0.35	0.99	0.70	0.30
		Relay	1.30	0.29	0.71	0.73	0.34	0.66
	5.3	Inter	1.19	0.54	0.46	1.08	0.59	0.41
		Relay	1.72	0.27	0.73	0.96	0.32	0.68
	13.3	Inter	1.32	0.46	0.54	1.18	0.51	0.49
		Relay	1.45	0.22	0.78	0.80	0.26	0.74
150	2.7	Inter	1.59	0.55	0.45	1.44	0.61	0.39
		Relay	1.19	0.22	0.78	0.65	0.26	0.74
	5.3	Inter	1.35	0.43	0.57	1.19	0.48	0.52
		Relay	1.42	0.25	0.75	0.79	0.29	0.71
	13.3	Inter	1.15	0.51	0.49	1.03	0.56	0.44
		Relay	0.96	0.35	0.65	0.54	0.40	0.60
			Cycle 2					
0	2.7	Inter	1.23	0.51	0.49	1.11	0.56	0.44
		Relay	1.27	0.18	0.82	0.69	0.21	0.79
	5.3	Inter	1.10	0.51	0.49	0.99	0.56	0.44
		Relay	1.13	0.24	0.76	0.63	0.29	0.71
	13.3	Inter	1.38	0.36	0.64	1.20	0.41	0.59
		Relay	1.17	0.16	0.84	0.64	0.20	0.80

150	2.7	Inter	1.48	0.42	0.58	1.30	0.47	0.53
		Relay	1.23	0.19	0.81	0.67	0.23	0.77
	5.3	Inter	1.41	0.36	0.64	1.23	0.41	0.59
		Relay	1.14	0.19	0.81	0.63	0.22	0.78
	13.3	Inter	1.44	0.28	0.72	1.23	0.32	0.68
		Relay	1.23	0.18	0.82	0.67	0.22	0.78
					Cycle 3			
0	2.7	Inter	1.02	0.58	0.42	0.94	0.63	0.37
		Relay	1.42	0.32	0.68	0.80	0.37	0.63
	5.3	Inter	1.04	0.50	0.50	0.94	0.55	0.45
		Relay	1.46	0.28	0.72	0.82	0.33	0.67
	13.3	Inter	1.14	0.44	0.56	1.01	0.50	0.50
		Relay	1.24	0.36	0.64	0.70	0.41	0.59
150	2.7	Inter	1.41	0.45	0.55	1.25	0.51	0.49
		Relay	1.23	0.25	0.75	0.68	0.29	0.71
	5.3	Inter	1.33	0.35	0.65	1.16	0.40	0.60
		Relay	1.25	0.22	0.78	0.69	0.26	0.74
	13.3	Inter	1.12	0.32	0.68	0.97	0.37	0.63
		Relay	1.30	0.32	0.68	0.74	0.37	0.63

†: Corresponding monocrop corn and peanut densities.

°: Average over five peanut densities (5, 10, 20, 40, and 80 plants m^{-2}).

Table B-7. Land equivalent ratio (LER) and area-time equivalency ratio (ATER) with respect to reproductive yield per hectare based on corresponding† monoculture yields in the inter- and relaycropping systems in three cycles of experimentation on a Malaysian histosol.

Nitrogen ($kg\ ha^{-1}$)	Corn density ($plants\ m^{-2}$)	System (cropping)	LER: Peanut density ($plants\ m^{-2}$) 5	10	20	40	80	ATER: Peanut density ($plants\ m^{-2}$) 5	10	20	40	80
			Cycle 1									
0	2.7	Inter	1.06	0.61	0.68	0.89	1.14	0.96	0.59	0.64	0.85	1.11
		Relay	1.10	1.12	1.24	0.90	0.93	0.60	0.63	0.68	0.50	0.53
	5.3	Inter	1.04	0.89	0.79	0.95	1.29	0.92	0.80	0.75	0.86	1.25
		Relay	1.40	1.84	2.07	1.80	1.80	0.77	1.01	1.14	1.01	1.00
	13.3	Inter	1.29	1.31	1.54	0.98	1.52	1.13	1.14	1.34	0.91	1.40
		Relay	1.64	1.16	1.33	1.02	1.46	0.89	0.63	0.72	0.58	0.82
150	2.7	Inter	1.16	1.68	1.37	1.20	1.37	1.03	1.48	1.24	1.10	1.23
		Relay	1.13	1.38	1.37	1.26	1.23	0.61	0.77	0.74	0.69	0.67
	5.3	Inter	1.42	1.07	1.09	1.25	1.09	1.24	0.93	0.96	1.16	0.95
		Relay	1.29	1.31	1.47	1.39	1.53	0.70	0.75	0.82	0.79	0.85
	13.3	Inter	1.04	1.03	1.50	1.30	1.28	0.88	0.89	1.28	1.14	1.10
		Relay	1.15	1.50	1.53	1.41	1.22	0.64	0.83	0.85	0.80	0.69
			Cycle 2									
0	2.7	Inter	1.09	0.79	1.28	1.03	1.25	0.96	0.73	1.19	0.94	1.17
		Relay	1.19	0.95	1.17	1.10	1.33	0.64	0.51	0.64	0.60	0.73
	5.3	Inter	1.10	0.78	0.81	1.15	0.97	0.98	0.73	0.74	1.06	0.92
		Relay	0.92	0.97	0.97	1.17	0.98	0.50	0.53	0.55	0.65	0.56
	13.3	Inter	1.12	0.61	0.91	1.28	1.38	0.96	0.56	0.83	1.17	1.28
		Relay	0.85	0.75	0.83	0.78	0.74	0.46	0.40	0.45	0.43	0.41

150	2.7	Inter	1.45	1.62	1.37	1.62	1.45	1.26	1.41	1.24	1.42	1.28
		Relay	1.30	1.33	1.16	1.22	1.42	0.71	0.72	0.63	0.66	0.77
	5.3	Inter	1.36	1.35	1.20	1.34	1.24	1.20	1.17	1.03	1.16	1.06
		Relay	1.22	1.16	1.11	1.21	0.80	0.66	0.63	0.60	0.65	0.43
	13.3	Inter	1.19	1.06	1.09	1.26	1.28	1.00	0.90	0.95	1.06	1.09
		Relay	1.19	1.15	1.07	1.31	0.88	0.64	0.62	0.58	0.71	0.47
			- - - - - - - - - - - - - - - - Cycle 3 - - - - - - - - - - - - - - - -									
0	2.7	Inter	0.75	0.73	1.28	0.87	1.00	0.67	0.68	1.22	0.83	0.97
		Relay	1.61	1.93	2.06	1.84	1.63	0.90	1.09	1.20	1.05	0.94
	5.3	Inter	0.64	0.69	0.85	0.63	0.67	0.57	0.65	0.82	0.60	0.64
		Relay	1.31	1.53	1.31	1.59	1.56	0.74	0.86	0.77	0.92	0.91
	13.3	Inter	0.72	0.74	0.93	0.77	1.05	0.64	0.65	0.86	0.72	0.95
		Relay	1.03	1.45	1.82	1.17	1.15	0.61	0.80	1.07	0.67	0.66
150	2.7	Inter	1.31	1.37	1.12	1.47	1.46	1.16	1.22	1.00	1.35	1.33
		Relay	1.33	1.48	1.22	1.58	1.27	0.73	0.82	0.68	0.89	0.72
	5.3	Inter	1.17	1.30	1.16	1.05	1.30	1.02	1.14	1.00	0.93	1.17
		Relay	1.21	1.38	1.18	1.51	1.36	0.68	0.76	0.66	0.85	0.76
	13.3	Inter	0.88	0.93	0.84	1.01	1.19	0.74	0.80	0.73	0.89	1.07
		Relay	1.44	1.30	1.24	1.40	1.50	0.82	0.73	0.69	0.79	0.83

†: Corresponding monocrop corn and peanut densities.

Table B-8. Average° land equivalent ratio (LER) and area-time equivalency ratio (ATER) with respect to reproductive yield per hectare based on corresponding† monoculture yields, and their respective relative yield proportions in the inter- and relaycropping systems in three cycles of experimentation on a Malaysian histosol.

Nitrogen (kg ha^{-1})	Corn density (plants m^{-2})	System (cropping)	LER°			ATER°		
			LER	Peanut proportion	Corn proportion	ATER	Peanut proportion	Corn proportion
			Cycle 1					
0	2.7	Inter	0.88	0.74	0.26	0.83	0.78	0.22
		Relay	1.06	0.25	0.75	0.57	0.29	0.71
	5.3	Inter	0.99	0.61	0.39	0.92	0.66	0.34
		Relay	1.78	0.24	0.76	0.99	0.28	0.72
	13.3	Inter	1.33	0.47	0.53	1.18	0.52	0.48
		Relay	1.32	0.22	0.78	0.73	0.26	0.74
150	2.7	Inter	1.35	0.48	0.52	1.22	0.53	0.47
		Relay	1.27	0.19	0.81	0.70	0.23	0.77
	5.3	Inter	1.18	0.42	0.58	1.05	0.47	0.53
		Relay	1.40	0.27	0.73	0.78	0.32	0.68
	13.3	Inter	1.23	0.31	0.69	1.06	1.36	0.64
		Relay	1.36	0.29	0.71	0.76	0.33	0.67
			Cycle 2					
0	2.7	Inter	1.09	0.59	0.41	1.00	0.64	0.36
		Relay	1.15	0.15	0.85	0.62	0.18	0.82
	5.3	Inter	0.96	0.62	0.38	0.89	0.67	0.33
		Relay	1.00	0.25	0.75	0.56	0.29	0.71
	13.3	Inter	1.06	0.53	0.47	0.96	0.58	0.42
		Relay	0.79	0.17	0.83	0.43	0.21	0.79

150	2.7	Inter	1.50	0.40	0.60	1.32	0.45	0.55
		Relay	1.29	0.15	0.85	0.70	0.18	0.82
	5.3	Inter	1.30	0.33	0.67	1.12	0.38	0.62
		Relay	1.10	0.15	0.85	0.59	0.18	0.82
	13.3	Inter	1.18	0.25	0.75	1.00	0.29	0.71
		Relay	1.12	0.14	0.86	0.61	0.17	0.83
			- - - - - - - - - - - - - - Cycle 3 - - - - - - - - - - - - - -					
0	2.7	Inter	0.93	0.70	0.30	0.87	0.74	0.26
		Relay	1.81	0.36	0.64	1.04	0.41	0.59
	5.3	Inter	0.70	0.72	0.28	0.66	0.76	0.24
		Relay	1.46	0.40	0.60	0.84	0.45	0.55
	13.3	Inter	0.84	0.53	0.47	0.76	0.58	0.42
		Relay	1.32	0.41	0.59	0.76	0.47	0.53
150	2.7	Inter	1.35	0.51	0.49	1.22	0.60	0.44
		Relay	1.38	0.28	0.72	0.77	0.33	0.67
	5.3	Inter	1.20	0.39	0.61	1.05	0.44	0.55
		Relay	1.33	0.28	0.72	0.74	0.32	0.68
	13.3	Inter	0.97	0.34	0.66	0.84	0.39	0.61
		Relay	1.37	0.30	0.70	0.77	0.35	0.65

†: Corresponding monocrop corn and peanut densities.

°: Average over five peanut densities (5, 10, 20, 40, and 80 plants m^{-2}).

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BIOGRAPHICAL SKETCH

Ahmad b. Selamat was born on March 29, 1953, in Bukit Gambir, Muar, Johor, Malaysia. He received primary (1960-1965), lower secondary (1966-1968), and upper secondary (1969-1972) education at Sekolah Kebangsaan Bukit Gambir, Sekolah Menengah Rendah Kebangsaan Bukit Gambir, and Sekolah Alam Shah Kuala Lumpur, respectively. He entered Universiti Pertanian Malaysia (University of Agriculture, Malaysia) in June, 1973, and then graduated with B.Sc. (Agriculture) in April, 1977.

He joined the Malaysian Agricultural Research and Development Institute (MARDI) as a research officer in June, 1977. He worked at the Alor Star MARDI Research Station in 1977 to 1979 and dealt with the local verification trials on rice and vegetables. He was then transferred to the Integrated Peat Research Station (IRPS), MARDI, Pontian, Johor, in 1979. In Pontian, he worked on the local verification trials on vegetable, pineapple (peat soil), cocoa, and coffee. He was also the head of IPRS while in Pontian.

In 1981, he was awarded the MARDI scholarship and entered (1982) the University of Florida and obtained his M.S. degree (with major in agronomy and minor in statistics) in 1983. He began pursuing his Ph.D. program in 1983. After his Ph.D. qualifying examination, he returned to his home country. While working as a research officer at

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He is a member of the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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Professor of Agronomy

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